

# PUBLIC ROADS

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BUREAU OF PUBLIC ROADS



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A ROAD CONDITION AND SUBGRADE SURVEY PARTY IN THE FIELD

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BUREAU OF PUBLIC ROADS

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# SUBGRADE STUDIES OF THE BUREAU OF PUBLIC ROADS<sup>1</sup>

Reported by C. A. HOGENTGLER, Highway Engineer; I. B. MULLIS, Associate Engineer of Tests; and A. C. BENKELMAN, Assistant Research Specialist, all of the Division of Tests, United States Bureau of Public Roads

AT THE present time very little information concerning the influence of the subgrade on pavement behavior is assembled in such form as to be utilized by the highway engineer. Until recently, research on subgrades has been devoted largely to laboratory tests and gratifying progress has been made. Practical field and laboratory tests have been developed for measuring volumetric change and supporting value, assuming that these are primary influencing characteristics of subgrade soils. In accordance with this assumption soils with high moisture equivalents and shrinkage values would be classed as poor subgrade and those having comparatively low values in these tests would be classed as good subgrade.

## DATA RELATING SUBGRADE TO PAVEMENT CONDITION NEEDED

However, our knowledge of the relation between pavement condition and the subgrade is meager. Little is known of the relative life or condition of pavements laid on good and questionable subgrades. Do increased cracking, breaking, rutting, raveling, and unevenness accompany bad subgrades? How are maintenance and operating costs influenced by subgrade condition? What additional initial expenditure on account of poor subgrade would be warranted by the difference in renewal, maintenance, and operating costs? Shall this additional expenditure be made on the subgrade, the pavement, or both? Can less thickness of pavement or a different type be used when the moisture equivalent is 15 instead of 30, and what test values bound the limits of good, intermediate, and poor subgrade?

Examination of existing reports reveals but few references to soil-test results translated into terms of road condition. The most specific of these is found in an article by A. C. Rose.<sup>2</sup> As a result of observations in the Pacific Northwest he states that when the lineal shrinkage of a soil exceeded 5 per cent, the pavement showed degrees of deterioration corresponding to the amount by which the shrinkage exceeded this value and, conversely, that when the lineal shrinkage was less than 5 per cent the pavements were found to be in relatively good condition.

The average highway engineer, without knowledge of any soil tests, can determine by inspection the location of subgrade of questionable character with a fair degree of precision. Remedial measures, however, based upon the qualitative analysis of the subgrades are yet to be determined.

The Highway Research Board has found that the use of steel reinforcement in concrete slabs is one method of compensating for bad subgrade, but no correlation of the amount, type, or design of the reinforcement with laboratory soil tests has been made. Some engineers believe the remedy lies in the use of subbase,

but definite information regarding the type and thickness is lacking. The relative economy of subbase and special pavement designs for specific cases must be determined.

The aim of the subgrade studies of the Bureau of Public Roads is to furnish the highway engineer with definite information on these questions. Its objects as submitted to the committee on tests of the American Association of State Highway Officials are to determine:

1. The practicability of varying the type or design of road surface to suit subgrade conditions.
2. The efficiency of various types of drainage, subgrade treatment and subbase.
3. The relative economy of subgrade correction (treatment, drainage or subbase) and change in pavement design (type, thickness or features) as compensation for varying subgrade conditions.

## EXISTING INFORMATION AND METHODS INSUFFICIENT AS BASIS FOR CONCLUSIONS

A proposed method of attack was to correlate studies of roads in service with United States Bureau of Soils data, laboratory tests on subgrade soils, and cost records. The procedure required a classification of soils with regard to their physical properties, but laboratory tests then in use did not yield results which were adapted to a simple classification. To aid in solving these problems Dr. Charles Terzaghi, of the Massachusetts Institute of Technology, was retained by the bureau as research consultant. He suggested a preliminary grouping of soils based on region and simplified soil tests, and a final classification based on refined tests of representative samples of the preliminary groups.<sup>3</sup> He summed up the value of laboratory and field work as follows:

Laboratory tests identify the raw materials of soils and are of value only for soil classification. Tests on specially prepared specimens in the laboratory do not necessarily indicate the physical properties of cracked, crumbled, or compacted soils in the field. Nor can laboratory tests, alone, indicate the efficiency of a soil when used as subgrade.

Only by field surveys can the influence of subgrade on pavements be determined. Whether or not a certain type or design of pavement is adequate for a given subgrade condition can be determined only by a study of the specific pavement laid on the given subgrade.

This statement indicates the importance of studies of roads in service, but such studies are a new departure in highway research and standardized methods of procedure did not exist. A tentative working plan for making road surveys has been developed by the bureau and has been tried on several roads to determine its workability. The complete outline with a description and discussion of the road-survey procedure follows.

<sup>1</sup> A report to the committee on structural design of highways, National Research Council, December, 1926.

<sup>2</sup> Field Methods Used in Subgrade Surveys, PUBLIC ROADS, vol. 6, No. 5, July, 1925.

<sup>3</sup> Simplified Soil Tests for Subgrades and Their Physical Significance by Dr. Charles Terzaghi, PUBLIC ROADS, vol. 7, No. 8, October, 1926.

## PROCEDURE FOR SUBGRADE STUDIES OUTLINED

## I. Studies of roads in service, including experimental roads.

## A. Field surveys.

1. Selection of pavements for condition surveys with regard to subgrade variables as follows:
  - a. Variation in soil type (as shown by county maps of the United States Bureau of Soils) under the same road or under roads comparable as to age, traffic, climate, and design.
  - b. Special features (drainage, subgrade treatment or subbase) under only part of the same road or under different roads comparable as to age, traffic, and design.
  - c. Same soil type or subgrade features under roads different in design or type but comparable as to age, traffic, or climatic influences.
2. Detailed procedure for pavement and subgrade surveys to include procurement of—
  - a. Record of pavement condition in detail (cracking, breaking, rutting, settlement, disintegration, unevenness, replacements, etc.).
  - b. Record of cut or fill, grade, excessive moisture, etc., and soil series, type, and layer. Soil inspection to be made by an experienced soil surveyor.
  - c. Samples of subgrade soil for laboratory test.
  - d. Exact limits of special features (drainage, treatment, subbases) and soil types.
  - e. Samples of road surface and also original soils for sand-clay and similar roads.

## B. Analysis of pavement condition records including those now available and those to be secured.

1. Classification of pavements with regard to climate, age, traffic, type, and design.
2. Grouping of pavements with regard to subgrade soil classification using the United States Bureau of Soils terminology.
3. Grouping of pavements with regard to subgrade soil classification based on laboratory tests.
4. Grouping of pavements with regard to artificial drainage, subgrade treatment, and subbase.
5. Tabulation of pavement characteristics in cuts, on original ground surface and on fills, in regard to the four preceding classifications.

## II. Subgrade laboratory procedure.

## A. Routine tests and classification.

1. Determination of series, type, and general characteristics of the soil by reference to maps and reports of the United States Bureau of Soils.
2. Preliminary classification.
  - a. Color determinations (optional) on both wet and dry pats for that fraction of the soil which passes the 0.5-millimeter screen.
  - b. Sedimentation (optional). Settlement of soil after being thoroughly mixed with water in a 50-centimeter graduate. For each soil type samples are to be grouped according to color and sedimentation characteristics. Samples will be selected from these groups for routine testing in order to reduce laboratory testing to a reasonable amount.
  - c. Revised mechanical analysis. Determination of fractions of soils passing the 0.5, 2, and 5 millimeter screens. Coarse material classified as rounded, angular, etc.
  - d. Lower liquid limit for 0.5-millimeter fraction.<sup>4</sup>
  - e. Lower plastic limit for 0.5-millimeter fraction.
  - f. Shrinkage limit for 0.5-millimeter and 2-millimeter fractions.
  - g. Shrinkage rate for 0.5-millimeter and 2-millimeter fractions.
  - h. Slaking value for 0.5-millimeter fraction.<sup>5</sup>
  - i. Moisture equivalent for 2-millimeter fraction.
  - k. Volumetric change computed at moisture equivalent percentage from shrinkage limit and ratio on 2-millimeter fraction.
3. Final classification. Terzaghi swelling test and bearing power determination on representative soil samples only.
  - a. Modulus of compression.
  - b. Modulus of expansion.
  - c. Coefficient of permeability.

## II. Subgrade laboratory procedure—Continued.

## A. Routine tests and classification—Continued.

## 3. Final classification—Continued.

- d. Compressive strength of oven-dried specimens.
- e. Compressive strength of specimens compacted from lower liquid limit to pressure of 3 kilograms per square centimeter.

## 4. Additional tests.

- a. Special tests as desired or requested.

## B. Research in soil tests. Additional work as follows:

1. Lower liquid limit.
  - a. Determination of air content of representative samples at lower liquid limit.
  - b. Comparison of results of standard lower liquid limit test with those obtained with samples on which a vacuum is produced.
  - c. Development of an automatic device for making the lower liquid limit test.
2. Lower plastic limit.
  - a. Influence of final thread diameter on results.
  - b. Comparison of results when threads are rolled on paper (different kinds) and glass.
3. Slaking value.
  - a. Influence of temperature.
  - b. Influence of size and form of specimen.
  - c. Development of standard test.
4. Volumetric change.
  - a. Study of errors of observation connected with the mercury and paraffin method for determining the volume of soils.
  - b. Development of a method for determining the volume of soils in a natural or undisturbed condition.
5. Specific gravity determinations.
  - a. Influence on result when cold water, boiling water, and different organic liquids are used.
6. Preparation of test specimen.
  - a. Development of a method for preparing soil powder and water, excluding air.
7. Swelling tests.
  - a. Influence of air content in soil samples.
8. Bearing power tests.
  - a. Influence of size of sample.
  - b. Influence of size of bearing block.
  - c. Improvement of apparatus to allow release as well as application of load.

## C. Soil classification.

1. Preliminary classification of all routine soil samples.
  - a. Grouping of soils by regions with regard to geological and climatic conditions.
  - b. Classification of each regional group with regard to lower liquid limit as follows:

Class	Lower liquid limit
O	10.0 to 14.2.
I	14.2 to 20.0.
II	20.0 to 28.4.
III	28.4 to 40.0.
IV	40.0 to 56.8.
V	56.8 to 80.0.
VI	80.0 to 113.6.

- c. Subdivision of each lower liquid limit class with regard to plasticity index as follows:

Class	Plasticity index
a	Less than 1.
b	1 to 7.
c	7 to 14.
d	14 to 21.
e	21 to 28.
f	28 to 35.
g	35 to 42.
h	42 to 49.

- d. Further subdivision, should some other simple test, such as dye adsorption, be found to identify soil characteristics other than those disclosed by the Atterberg plasticity tests.
- e. Identification of each soil type according to the United States Bureau of Soils system and terminology. Thus, test results and other soil data published by the Bureau of Soils can be utilized.
2. Final classification according to the Terzaghi swelling tests of representative samples from each of the preliminary groups.
  - a. Modulus of compression.
  - b. Modulus of expansion.
  - c. Coefficient of permeability.

<sup>4</sup> Adaptation of Atterberg Plasticity Test for Subgrade Soils, by A. M. Wintermyer, PUBLIC ROADS, vol. 7, No. 6, August, 1926.

<sup>5</sup> Slaking Value Test, a paper presented by Prof. F. H. Eno at the sixth annual meeting of the Highway Research Board, National Research Council, December, 1926.

### III. Additional investigation.

- A. Determination of basis of correction for influence of coarse materials in subgrade. Since laboratory tests are confined to that fraction of soil passing the 0.5 millimeter screen, the characteristics of an entire subgrade soil sample can not be learned until a basis for correction for both round and angular grains has been established for all tests.
- B. Determination of relative efficiency of various types and designs of pavements with different loads and subgrade supports. Soil pressure cells to be installed under selected pavements at the time of construction. From each location, subgrade soil samples will be obtained and sent to the laboratory for identification and classification. At subsequent periods observations will be made as follows:
  1. On concrete pavements the subgrade support to be determined with pressure cells and the fiber deformation determined with graphic strain gauges for wheel loads of different magnitude.
  2. Macadam and bituminous pavements.
    - a. Determination of subgrade support and local pavement deflection for wheel loads of different magnitude.
    - b. Supplemental investigations to determine the magnitude of repeated deflections which macadam and bituminous pavements can safely withstand.
- C. Evaporation, freezing, and other tests relating to the physics of the subgrade.
- D. Detailed investigation of specific road failures to determine the conditions which cause failures.
- E. Experimental sections. Whenever the opportunity occurs, sections to be constructed to test corrective measures for questionable subgrade conditions. Future observations will be made on these sections to determine their efficiency.

### IV. Digest of preceding investigations.

- V. Correlation of road studies (condition surveys) with soil classification (laboratory studies).
  - A. Influence of type of soil on pavement behavior.
  - B. Influence of soil characteristics (variations within types) on pavement behavior.
  - C. Determination of type and design of pavement for a given subgrade condition.
  - D. Determination of efficiency of various types of drainage, subgrade treatment, and subbase.
- VI. Correlation of road studies and subgrade investigations with office records.
  - A. Influence of road condition on maintenance costs.
  - B. Influence of type of soil on maintenance costs and life of pavement.
  - C. Influence of soil characteristics on maintenance costs and life of pavement.
  - D. Relative cost of compensating for variation in subgrade condition with:
    1. Change in type or design of pavement.
    2. Drainage, subgrade treatment or subbase.
    3. Change in both surface and subgrade.

It will not be possible to start all of the proposed investigations immediately. All those having a bearing on the subject have been listed so that a definite working plan for evaluating subgrade variables can be presented. Every effort is being made to start the road condition surveys as soon as possible.

### ROAD CONDITION SURVEYS TO BE MADE

The idea of assembling information on the relative influence of the various factors affecting pavement behavior is not new. Extensive surveys covering the entire State highway system have been carried on as part of the routine work in Pennsylvania, North Carolina, and Washington, while a very complete survey has been made in California.<sup>6</sup> The Highway Research Board has also assembled considerable valuable information in connection with its study of the economic value of steel reinforcement in concrete road surfaces.<sup>7</sup>

The Bureau of Public Roads and others interested in highway research have advocated the use of condition surveys in connection with subgrade studies.<sup>8</sup> As part of the discussion on structural design of pavements at the 1925 meeting of the Highway Research Board, Clifford Older<sup>9</sup> directed attention to the need of a more comprehensive study when he suggested a condition survey with the view of correlating soil classification and pavement condition. The Michigan State highway department is now engaged in an investigation of this kind.<sup>10</sup>

To make a survey of the many thousands of miles of roads now in existence would be too great a task. Accordingly, roads must be selected which will furnish the maximum amount of information with the smallest mileage of inspections.

Study of the effect of subgrade is the primary object, but it is appreciated that the data will yield information on every variable affecting pavement behavior. Before the influence of subgrade can be determined, the effect of other variables must be understood and this can be accomplished by confining observations to roads with but one variable. Variation in the road surface itself presents a difficulty but it is expected that valuable information will be derived from such experiments as the Virginia demonstration road,<sup>11</sup> in which the influence of climatic, construction, and curing variables on various designs are being determined.

If the resulting information is to be conclusive, it is essential that the roads inspected shall have acquired sufficient age or shall have been subjected to enough traffic to have developed defects, and it will also be necessary to pay particular attention to the modern types of construction, devoting only a limited amount of study to the obsolete types. It seems advisable to select only those roads with a recorded history of design and construction, as the analysis of any condition survey is a complex problem even when all data are available. In order to simplify and expedite the work, the field surveys will be of three separate classes.

Class 1 surveys will deal with roads which have failed only in part of their length. An effort will be made to determine if the failures were caused by soil characteristics which can be foreseen in future road construction. These studies will be made in detail from the viewpoint of the geologist, the soil scientist, and the highway engineer.

Class 2 surveys will deal with roads where corrective measures have been used for offsetting undesirable subgrade conditions on part of the length. These corrective measures may consist of a change in type or design of pavement, subgrade treatment, subbase, or special artificial drainage. The object of the surveys will be to determine the relative efficiency of the various corrective measures now in use. Class 1 and class 2 surveys will be carried on by separate parties.

Class 3 surveys will deal with roads laid on different types of soil. The object will be to determine the relative frequency with which pavement defects occur on different kinds of soil. Roads will be listed with regard to age, type, design, traffic, and climate. The

<sup>6</sup> Practical Field Tests for Subgrade Soils, by A. C. Rose, PUBLIC ROADS, vol. 5, No. 6, August, 1924.

<sup>7</sup> Proceedings of the Fifth Annual Meeting of the Highway Research Board, Dec. 3-4, 1925, Part I, pp. 129-130.

<sup>8</sup> Survey of Soils and Pavement Condition in Progress in Michigan, by V. R. Burton, PUBLIC ROADS, vol. 7, No. 4, June, 1926.

<sup>11</sup> Virginia Building Demonstration Road, PUBLIC ROADS, vol. 7, No. 6, August, 1926.

<sup>6</sup> Report of a Study of the California Highway System by the U. S. Bureau of Public Roads, 1926.

<sup>7</sup> Report of Investigation of the Economic Value of Reinforcement in Concrete Roads, by C. A. Hogentogler: Part 2, Proceedings of the Fifth Annual Meeting of the Highway Research Board, December, 1925.

United States Bureau of Soils maps will then be consulted and the final list for field study will embrace those roads which include the greatest number of soil variables. For study of maintenance costs as influenced by the subgrade various projects will be compared, each of the same age, type, and design and as nearly as possible subject to the same traffic and climate, but with different subgrade soils.

#### SURVEYS TO YIELD DETAILED INFORMATION ON ALL FACTORS

The condition survey records will show all pavement defects. On concrete roads there will be recorded all controlled and uncontrolled cracking, corner breaks, general breaking and surface checking, scaling, and

soil at points sufficiently close together to identify all existing soil types. Samples of the soil for laboratory analysis will be secured at the time of the inspection from both the subgrade and soil layers. The condition of the soil with respect to compaction and degree of saturation will also be noted as well as any changes in gradation, color, and character. Data will be recorded on water seepage in cuts and free water where its presence is indicated. It is intended to have a special soil survey made by a soil scientist where surveys have not been made by the Bureau of Soils and where any difficulty in determining the soil types is encountered.

#### STANDARD SYSTEM OF RECORDING TO BE USED

Figure 1 illustrates the symbols to be used and manner of recording the slab condition with respect to joints, cracks, corner breaks, general failures, raveling, and width of cracks and joints. Conventional symbols for indicating the classification of the corner breaks, general failures, and culverts, bridges, and cross-roads are also shown. The elevation of the pavement with reference to the adjacent terrain is shown continuously by a profile system. Other features are to be indicated as shown.

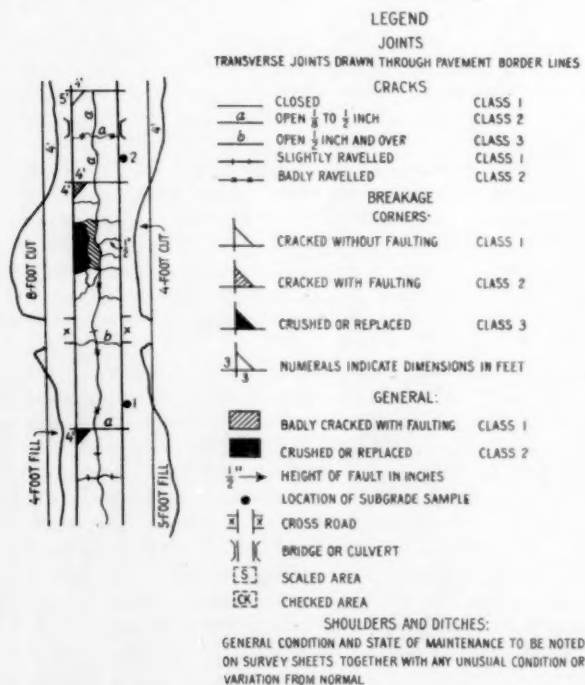


FIG. 1.—METHOD OF RECORDING AND SYMBOLS TO BE USED IN PAVEMENT CONDITION AND SUBGRADE SURVEYS

raveling. The width of the cracks and the degree of raveling, if any, are also important. A slab may be cracked badly and yet present a smooth, uniform surface; while another may be cracked to the same extent but be so uneven as to make early replacement necessary. Differences of this kind are to be noted in the reports. Information as to differences in condition is as important as the record of the breaks. All concrete pavements show surface defects; it is the magnitude and degree of these phenomena which merit attention in the survey.

The condition of the shoulders and ditches and the elevation of the shoulders of the roadway in relation to the pavement are points of particular interest both as to the condition of the surfacing and the subgrade. Information upon the general topography of the land adjoining the road and upon the nature and extent of the vegetation in the adjacent areas will be of value. Crossroads, bridges, and culverts are responsible in many cases for localized cracks and failures, and information as to their location is important.

The subgrade survey carried on in connection with the condition survey will require inspection of the

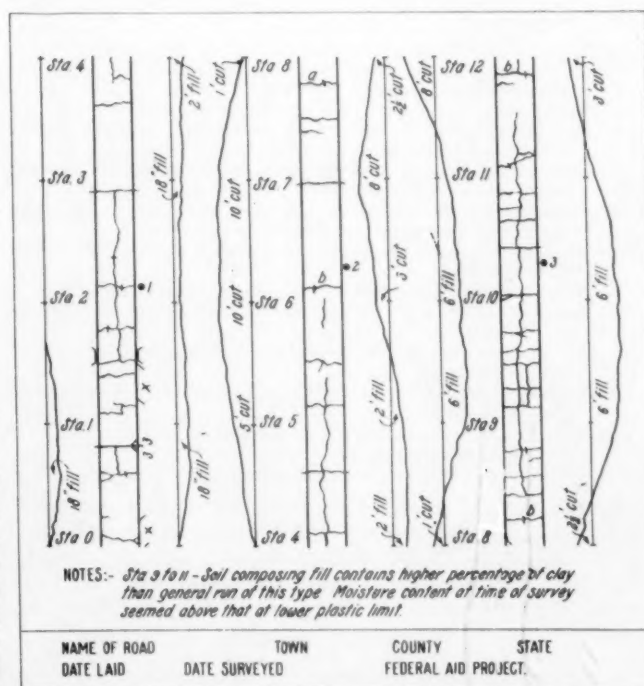


FIG. 2.—SAMPLE OF FIELD RECORD MADE ON ONE OF THE PRELIMINARY PAVEMENT CONDITION SURVEYS

The pavement condition party will consist of a chief, experienced in road construction, and three assistants. Two assistants will measure off and mark the stations on the road, while the engineer walks along the pavement with a log board and specially prepared forms and sketches pavement defects and other features previously mentioned. The fourth member of the party will inspect the subgrade and collect the soil samples. The form which has been prepared contains space for plotting 1,200 feet of pavement survey. (Fig. 2.)

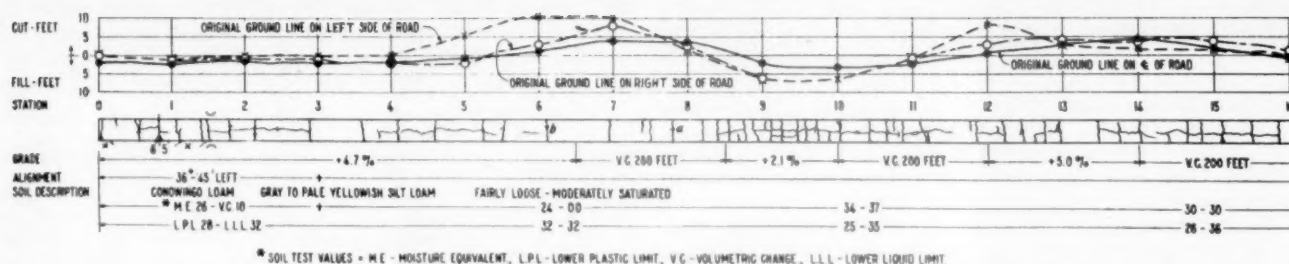


FIG. 3.—SAMPLE OF PERMANENT RECORD SHEET FOR RECORDING RESULTS OF PAVEMENT CONDITION AND SUBGRADE SURVEYS. THE PRESENT ROAD SURFACE IS REPRESENTED BY A HORIZONTAL LINE AND INFORMATION AS TO GROUND SURFACE IS PLOTTED RELATIVE TO THIS LINE

#### RECORDS TO BE IN FORM SUITABLE FOR PRESENT AND FUTURE USE

Permanent records of surveys are to be made on 24 by 36 inch sheets on which will be shown in detail the condition of the slab, the results of the soil analysis, and other pertinent information secured from the construction plans of the road. This will include the depth and length of the cuts and fills made prior to the construction of the pavement, the beginning and end of relocations, and the grade and alignment changes. Accurate correlation of condition survey information with that on the original road plans will depend on frequent checks between the new and old stationing.

The permanent detailed record will serve a number of purposes. It will be of immediate value as the basis for compiling the summary record and will greatly lessen work on future surveys. Figure 3 shows the details of a portion of such a chart, a single sheet of which is sufficient to record the data for 6,400 feet of pavement.

#### CONCLUSIONS TO BE BASED ON COMPARISONS OF SUMMARY RECORDS

The summary record is to be the analytical digest of each survey. It will present condensed information from which deductions may be drawn as to the variables in one road as compared with similar variables in

TABLE 1.—Typical summary record of condition survey

Soil type and location	Number of each	Length of pavement	Number of transverse cracks and joints	Average spacing of transverse cracks	Total length of longitudinal cracks	Pavement cracked longitudinally	Number of corner breaks		General breaking		Surface checking; number of checks per linear foot of pavement					Soil tests <sup>1</sup> (average values)			
							Class 1	Class 2	Class 1	Class 2	None	5	15	30	45	Moisture equivalent	Volume change	Lower plastic limit	Lower liquid limit
Conowingo loam:																			
Cut.....	8	1,400	39	36	750	52	1				84	10	6			22	11	26	29
Fill.....	8	3,500	108	32	2,520	72	4	3			65	15	14	5	0.6	24	16	26	28
Grade.....	3	1,000	26	39	510	51	3				57	17	14	12		25	17	23	27
Total.....		5,900	173	34	3,780	64	8	3			69	14	12	5	0.3	24	15	26	28
Manor loam:																			
Cut.....	14	4,275	86	50	1,370	32	2				35	39	27	7	2	20	5	28	29
Fill.....	12	4,675	70	67	3,000	64		1			40	26	22	10	2	21	5	29	29
Grade.....	4	1,900	50	38	950	48					67	24	6	8		19	10	23	23
Total.....		10,850	206	53	5,320	40	2	1			49	31	21	7	2	21	6	25	26
Chester loam:																			
Cut.....	9	2,000	32	62	1,100	55	2	1			30	47	11	6	6	22	12	26	27
Fill.....	8	3,625	58	63	2,430	67					53	20	17	8	2	21	9	27	27
Grade.....	4	1,125	17	66	780	69					27	15	23	29	6	29	23	27	27
Total.....		6,750	107	63	4,440	66	2	1			42	27	16	11	4	22	12	27	27
Louisa loam:																			
Cut.....	2	500	6	83	330	67					70	30				19	7	27	27
Fill.....	2	1,000	14	71	680	68					83	17				25	10	32	32
Grade.....		200	4	57	200	100					18	82							
Total.....		1,700	24	72	1,210	71	0				71	29				23	9	30	30
Iredell loam:																			
Cut.....	2	1,150	23	50	720	65					32	50	11	7		28	27	27	34
Fill.....	4	2,150	40	54	2,020	94	1	3			34	40	17	9		23	18	22	26
Grade.....																			
Total.....		3,300	63	53	2,740	83	1	3			33	44	15	8		25	20	24	29
Granville loam:																			
Cut.....	1	350	10	37	310	91	1				34	31	31	4		18	10	17	22
Fill.....	1	450	4	112	450	100					55			4.5		22	12	22	26
Grade.....	1	200	3	66	200	100					80	15	5			21	10	23	28
Total.....		1,000	17	60	960	96	1				61	14	12	3.5		20	11	21	25
All types:																			
Cut.....	36	9,675	196	49	4,580	48	6	1			37.8	36	18	5.2	2.0				
Fill.....	35	15,400	294	32	11,100	72	5	7			52.0	23	16	7.5	1.3				
Grade.....	13	4,425	100	44	2,640	60	3				52.5	23	12	11	1.5				
Total.....		29,500	590	50	18,320	62	14	8			47.5	27.5	16	7.3	1.6				

<sup>1</sup> Routine soil test procedure described on page 2 was adopted after this survey was made.

another. The form and extent of the summary record is shown in Table 1. The information will be obtained directly from the permanent record charts by scaling and totaling the lengths of the cuts, fills, and grade sections in each soil type. The original ground line will be used in the computation of vertical distances. In addition to the information shown in Table 1, there will be included data as to the geological character of the soil.

On many surveys, information concerning the effect of the soil type and of cuts and fills upon slab or surface condition will include a summary record of—

1. The width of cracks and joints.
2. The raveling at cracks and joints.
3. The faulting of slabs.
4. The scaling of the surface.

On other surveys information on the slab condition for different percentages of varying grades and alignment may be necessary for the proper interpretation of the results. The effect of depth of cut or fill may also be shown in the summary record.

The data to be contained in the summary records will permit relationships to be established between the slab or surface condition and the results of the soil tests. These relationships may be shown conveniently in diagrammatic form. For example, slab condition, percentage of longitudinal cracking, or number of corner breaks may be compared with the moisture equivalent or other test values.

#### SURVEYS TO BEGIN AT AN EARLY DATE

A field survey has been made in Virginia to determine the practicability of the methods outlined and it was found that the procedure is such that reasonably rapid work can be done in the field and laboratory. At the present time preliminary work is being done in cooperation with the Maryland State Roads Commission on the selection of roads for detailed survey during the coming summer. It is anticipated that surveys will be made in other States also.

All of the surveys undertaken will be carried on in cooperation with the State highway departments. The procedure as herein set forth is more or less tentative pending suggestions from the committee on tests of the American Association of State Highway Officials, the committee on structural design of roads of the Highway Research Board, and from all engineers interested in the highway problem. It is only by criticism and suggestion at this time that the final program of the investigation can be so framed that the results obtained will have the utmost value.

In addition to criticisms and suggestions, information on the following will be very much appreciated:

1. Location of roads where special drainage, subgrade treatment or subbase has been used under part of the surface.
2. Location of roads where widely different types of soils are found.
3. Existence of maintenance costs for roads which are similar in all respects except subgrade.
4. Existence of pavement condition survey data without regard to scope or purpose for which they were obtained.

#### SEVERAL STATES NOW CONSIDER SUBGRADE INFLUENCE

An examination of current practice in regard to subgrades seems pertinent at this point. Many States give little or no consideration to the subgrade, using

the same pavement designs for all conditions of support. Other States consider subgrade influence and compensate for it in various ways. The following information has been collected as to practice in some of the States:

**Arizona.**—Design of pavements dependent on subgrade rainfall, and temperatures. Type and thickness of pavement varied. Silty sand subgrade stabilized by adding mixture of gravel, caliche, and clay. Very fine dust subgrade (high cementing value) surfaced with clean, coarse gravel. Adobe soils surfaced with volcanic cinders, gravel, or similar available material. In some cases this treatment is used where surfacing is contemplated in the future.

**California.**—Subgrade soil tests are part of routine work on new construction jobs. Soils of low shrinkage and low moisture equivalent value are given preference for embankment. When moisture equivalent exceeds 30 per cent and the lineal shrinkage exceeds 5 per cent, subgrades are stabilized by the addition of sand, decomposed granite, or similar material.

**Oregon.**—Subgrade conditions generally determined by inspections by division engineers but in some cases laboratory tests are made. In some cases of questionable subgrade, sand sub-base (thickness dependent on soil shrinkage values) is used while in others (soft places or adobe) slab design is changed by adding reinforcement and reducing joint spacing.

**Washington.**—Subgrades are inspected by the construction engineer from the headquarters office and the district engineer. Questionable subgrades are compensated by increasing the thickness of paving, increasing or adding reinforcement, reducing the slab length or by adding gravel sub-base. Soft spots are dug out and replaced with gravel. Tile drains are used in wet and spongy places.

**Colorado.**—Subgrades are sampled and tested before pavement construction. Subgrades having a lineal shrinkage in excess of 5 per cent receive sand treatments of from 2 to 10 inches, depending on the extent to which the moisture equivalent exceeds 20 per cent.

**Minnesota.**—Clay subgrades are stabilized by the addition of sand and gravel and sand subgrades by an admixture of clay. In swampy sections fills are made with coarse-grained upland material, while deep wide ditches and a generous amount of tile are used to remove free water. Frost-boil failures are treated with admixtures of gravel. Special reinforcement is added to concrete pavements when the soil seems especially unstable. In some cases subgrades are oiled.

**Kansas.**—In isolated cases a sand sub-base has been used on gumbo soil.

**Massachusetts.**—Subgrade conditions are determined by visual inspection during the spring break-up, examination of material from test pits along the project, and by inspection during construction. Concrete pavements are not varied but foundations of stone and gravel and drainage are. Side drains are effectively used.

**Rhode Island.**—Subgrade conditions are determined by inspections made in the spring when frost is leaving the ground. When the road is on a new location samples of subgrade are secured for test. Sub-bases of gravel are used under penetration macadam or concrete roads as compensation for questionable subgrades.

**Connecticut.**—Double reinforcement in the slab and either sand, gravel, or stone sub-base connected to underground drains is used in locations where heaving is expected.

Maine, New Hampshire, New Jersey, and New York also compensate for questionable subgrade. This compensation includes gravel and stone sub-base, bituminous treatment of the subgrade, and steel reinforcement of the slab.

#### LARGE SAVINGS MAY RESULT FROM GREATER KNOWLEDGE OF SUBGRADES

Before undertaking an investigation of this kind it is pertinent to inquire as to the value of the results. It is not possible, of course, to form even an approximate estimate of the value of results in general, but the following instances will indicate the substantial value of the information it is proposed to obtain:

On one of the older Maryland roads (Beacon Hill-Elkton) about 30 per cent of one section is badly broken while an adjoining section is intact, variation in subgrade being responsible for the difference.

(Continued on p. 20)

# THE TREND OF HIGHWAY DESIGN

Reported by A. G. BRUCE, Highway Engineer, and R. D. BROWN, Associate Highway Engineer, Bureau of Public Roads

TO ONE familiar with the practice of the State highway departments the changes which have been made in the design of highways during recent years appear as no less remarkable than the notable changes in the volume and character of traffic by which they have been called forth. The general character of these changes is perhaps already well known to all highway engineers, but it is thought that a review in some detail of the practices now employed by each of the State highway departments, and their evolution during the past several years will be of interest as indicating the various shades of opinion on doubtful points and the degree of standardization obtained.

Opportunity for such a review is presented by the plans received from all States by the Bureau of Public Roads for Federal-aid projects, and the following analysis is based upon a large number of such plans received during the last six years:

**Crown.**—Nearly all the States now require that hard-surfaced pavements shall meet a surface trueness test, and this has resulted in greater care in finishing and has permitted a reduction in crown until the pavement now appears to be almost flat. The crown on cement concrete, brick, sheet asphalt, or any of the bituminous concrete pavements on rigid foundations is rarely more than one-fourth inch per foot. Some States have adopted one-eighth inch per foot, and two States use one-tenth inch per foot. The trend of practice is toward the latter amount, and it is probable that a 1-inch crown for a 20-foot hard pavement will soon be the prevailing practice. On sand-clay, gravel, and waterbound macadam roads the prevailing crown is one-half inch per foot and on bituminous macadam roads three-eighth inch per foot is quite general.

**Curvature.**—The trend toward easy horizontal curves and longer vertical curves is very apparent. A few years ago curves of 150 and 200 foot radius were common because of right-of-way difficulties and grading costs. Both engineering opinion and public sentiment have changed considerably and now the radius is seldom less than 500 feet, and some States have adopted 1,000 feet as the standard radius for main highways. Tangents at least 100 feet long are usually provided at bridges and between reverse curves.

**Vertical curves.**—The length of vertical curve has increased with the volume and speed of traffic which have made necessary greater sight distances. A rule used in many cases is that the length of vertical curve in stations shall equal one-half the algebraic difference of the approach grades in per cent. This rule results in a sight distance of approximately 450 feet, but on roads of primary importance the minimum sight distance on convex vertical curves is generally 500 feet and on secondary roads not less than 350 feet. Vertical curves are now used at all changes of grade on hard pavements, and on gravel and macadam, where the algebraic difference in grades is more than 0.5 per cent.

**Grades and alignment.**—The 1926 designs showed a continued upward trend of standards of alignment. The alignment is becoming straighter. Relocation of

crooked roads and the use of long, easy curves are becoming common. The grades have not been appreciably reduced; in fact, there appear to be more short, steep grades than heretofore. This is due in part to the fact that engineers now prefer to avoid sharp curvature even at the expense of steeper grades. There is no uniformity in the ruling grades adopted by the various States, but 5 per cent seems to be the prevailing practice. Grades of 7 per cent, however, are not uncommon, and in the Appalachian Mountain section short 9 per cent grades are still considered necessary.



A MODERN CONCRETE PAVEMENT. THE LONGITUDINAL JOINT PREVENTS IRREGULAR LONGITUDINAL CRACKS AND ACTS AS A GUIDE LINE FOR THE TRAFFIC

**Compensation of grades.**—There is no general acceptance of the theory that grades should be compensated for curvature on the modern highway designed for motor-driven traffic. This feature in grade design is, however, common in the Pacific Coast States.

Good practice seems to indicate that grades in excess of 5 per cent should be compensated on curves of less than 500-foot radius. The amount of compensation necessary depends upon several factors, including the length of the approach grade and its rate, the degree of curvature, length of curve, the amount of superelevation, the sight distance, and the general character of traffic expected. A simple rule that appears to have

considerable merit is to compensate grades over 5 per cent on all curves of less than 500-foot radius at the rate of 0.5 per cent for each 50-foot reduction in the radius below 500 feet.

**Superelevation and widening.**—Superelevation and widening of curves is now universally practiced, but there is no agreement in formula or method in the various States. A few States superelevate the roadway on all curves sharper than  $1^\circ$ , but the prevailing practice is decidedly more conservative. The average practice seems to be to superelevate all curves of less than 2,000-foot radius and to widen all curves of less than 800-foot radius. A maximum superelevation of 1 inch per foot of width, and a maximum widening of 4 feet represent the prevailing practice. The sub-



SUPERELEVATION AND WIDENING ON A CURVE IN A GRAVEL ROAD

committee on design of the American Association of State Highway Officials recommends, as a rule for widening, the formula suggested by J. T. Voshell, district engineer of the Bureau of Public Roads:

$$W = 2(R - \sqrt{R^2 - L^2}) + \frac{35}{R}$$

In which  $W$  = Widening in feet.

$R$  = Radius of curve in feet.

$L$  = Wheel base of vehicle in feet  
(20 feet recommended).

The same committee recommends for superelevation the formula  $E = 0.067 \frac{V^2}{R}$

In which  $E$  = Superelevation in feet per foot of width.

$V$  = Velocity in miles per hour (35 recommended).

$R$  = Radius of curve in feet.

**Width.**—Eighteen feet still predominates as the width of pavement on Federal-aid projects although pavements 20 feet wide and wider are not uncommon. Of the 3,643 miles of surfaced Federal-aid road brought to completion in the six months period preceding February 1, 1927, approximately half had 18-foot surfacing. Eight hundred and thirty-one miles were less than 18 feet wide, 1,809 miles were of 18-foot width, 900 miles were between 19 and 24 feet wide, 79 miles between 25 and 30 feet wide, and there were 24 miles of unusual construction not falling in the above classification.

**Subgrade.**—A majority of the States give little or no consideration to variations in the character of the subgrade, using the same pavement design throughout

each project. A few consider subgrade influence and compensate for it in varying degrees and manners.

The method of procedure in these States and the general subject of subgrade investigations is discussed in another report by the bureau.<sup>1</sup>

**Guard rail.**—In the minor features of highway design, such as culverts, guard rail, curbs, shoulders, etc., there do not appear to be any marked developments during the past year. The trend in guard-rail design continues to be toward the steel cable and woven wire and away from the wooden type. Where local conditions justify wooden guard rail, the plan of placing the rail at the elevation of the vehicle hub is gaining in favor. Some States are using steel and concrete guard-rail posts, but the prevailing practice is to use wooden posts. Some have adopted a new arrangement for fastening the wire cable to the post. Instead of running the cable through the post or bolting it in direct contact, a casting is used which holds the cable about 4 inches in front of the post. The claim is made that this arrangement adds a measure of safety, as vehicles will be less likely to hit the post.

**Curbs.**—Curbs at the edges of the roadway on bridges are being increased in height as a safety measure and as a protection to the bridge structure. Curbs 9 to 12 inches in height are used. Some States use even higher curbs and batter the face so that the vehicle hub will not scrape. Several bridge failures have occurred as a result of vehicles colliding with a main bridge member, and signs of collisions are so common on bridges as to indicate the necessity of protection.



DEVICE FOR OFFSETTING CABLE WIRES FROM SUPPORTING POSTS

**Shoulders.**—There is a decided trend toward wider shoulders on rural highways. On any main route the entire surface is needed to accommodate moving traffic. Even where traffic is light a vehicle parked on any portion of a surface designed to accommodate two lanes of traffic constitutes an element of danger, and if such parking is on a location with restricted sight distance the danger is a most serious one. The stopping of vehicles on account of breakdowns and other reasons is unavoidable and wider shoulders to accommodate such cases are justified. The greater width of graded roadway will permit surface widening on a consolidated foundation when required. At least 80 per cent of the current plans provide for shoulders more than 4 feet in width. Most of them provide for 5 feet, and a few require 6 feet or more.

**Grade crossing elimination.**—The railroad grade crossings are recognized as one of the most important factors in the highway problem, and the public is thoroughly aroused to the necessity for reducing this

<sup>1</sup> See Subgrade Studies of the Bureau of Public Roads on page 1 of this issue.

danger. It is recognized that all crossings can not be eliminated immediately and that an annual program must be worked out, abolishing the crossings in the order of their relative danger and taking into consideration the volume of rail and highway traffic.

During the past year 414 grade crossings have been eliminated on Federal-aid projects, making a total of 1,794 since Federal-aid work started. This is about 34 per cent of the grade crossings encountered. Of the crossings eliminated 1,076 were by relocation and the balance by means of overpass or underpass. Of the crossings eliminated during 1926, 202 were by relocation of the highway.

**Road types.**—Figures 1 and 2 show graphically the trend of type selection on Federal-aid projects. The data are shown by Federal fiscal years ending June 30 of the designated year. The figures would not be materially different had calendar years been used instead of fiscal years. Figure 1 shows the total mileage of the various types of completed Federal-aid projects, and also the mileage completed during the fiscal year 1926. Gravel easily predominates with 38.7 per cent of the total, and cement concrete is second with 20.3 per cent. These two types also predominated in 1926 with almost the same ratios, namely, gravel 38 per cent and cement concrete 24 per cent. Sand-clay mileage is 9.3 per cent of the total but only 6.3 per cent of the 1926 mileage, indicating that this type is not holding its former popularity. The mileage of this type has been steadily decreasing on Federal-aid work since 1922, and for new work is now practically confined to Alabama, Georgia, and South Carolina. Waterbound macadam also shows a decreasing popularity, being 2 per cent of the grand total and only 0.7 per cent of the 1926 mileage; but bituminous macadam forms a larger percentage of the 1926 work than of the total mileage. Bituminous concrete maintains approximately the same position in the 1926 work that

it occupies in the total mileage, but brick dropped considerably. Comparison of the mileage completed each year since 1920 is shown in Figure 2.

**Concrete pavement design.**—Since the use of Portland cement concrete for pavement surfaces is a comparatively recent development, it is natural that more changes are to be found in the design of this type of pavement than in other types. Tables 1 and 2 summarize the general practice in 1926. The most important change is in the shape of the cross section. Prior to the season of 1921 all Federal-aid concrete projects provided for pavements of uniform thickness or of less depth at the edges than at the center. In 1921 the State Highway Department of Arizona submitted three projects involving the unique idea of constructing concrete pavements with the edges thicker than the center. During 1921 and 1922 the Pittsburg and Bates test roads were constructed and the results of the tests were widely published, with the result that in 1922 over 5 per cent of the concrete pavement designs for Federal-aid projects were of the thickened-edge type. In 1923 the percentage of thickened-edge designs increased to 46 per cent, in 1924 to 73 per cent, in 1925 to 80 per cent, and in 1926 to 81 per cent. In mileage of roads the percentage of the thickened-edge type would be much greater because the uniform-thickness and thin-edge designs are mostly on short projects.

While the thickened-edge section has been almost unanimously accepted in principle by the State highway departments, there is still a notable lack of uniformity in the dimensions of the section used in various States which can not be wholly accounted for by varying requirements of loading and subgrade conditions. The difficulty encountered in properly shaping and consolidating the subgrade has had considerable effect in producing these variations. A study of the designs submitted to the bureau during 1926 shows that in

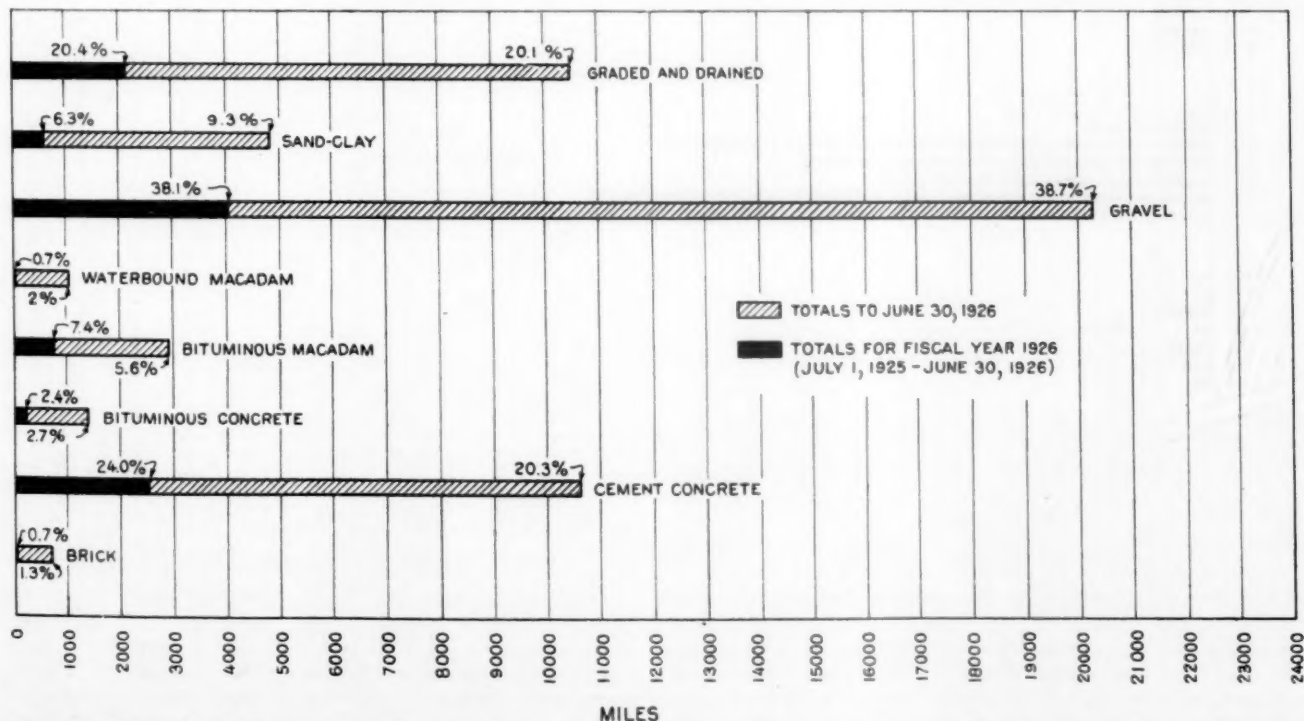


FIG. 1.—MILEAGE OF FEDERAL-AID ROADS COMPLETED BY TYPES TO JUNE 30, 1926, AND DURING THE FISCAL YEAR 1926

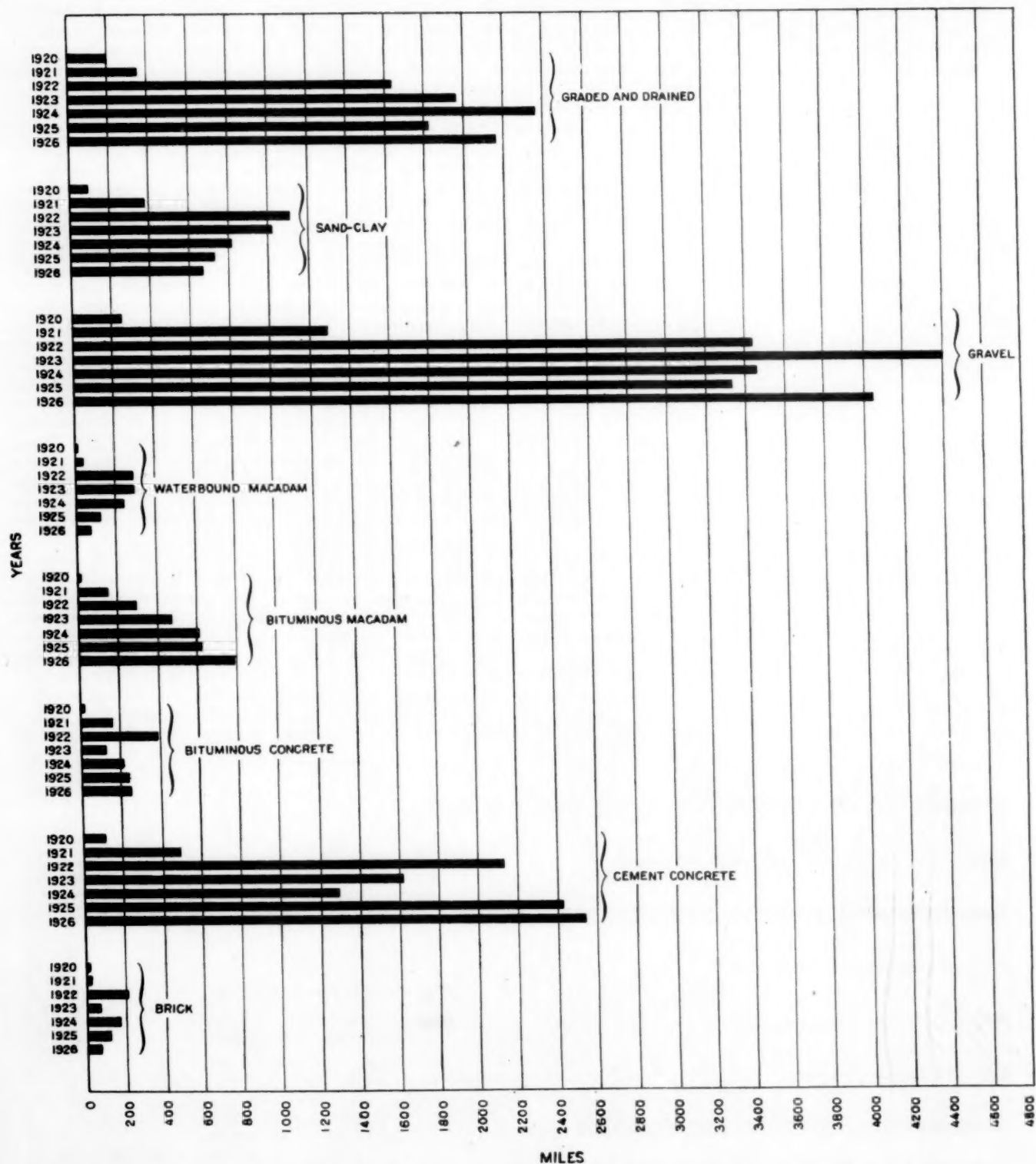


FIG. 2.—MILEAGE OF EACH TYPE OF ROAD CONSTRUCTED WITH FEDERAL AID EACH FISCAL YEAR SINCE 1920

15 States the increase in thickness is made in the outer 2 feet of the pavement, while in 10 States the increase is made in the outer 3 feet. In 4 States the transition is made in the outer 4 feet. Six States obtain the thickened edge by using a curved subgrade and a surface crown of longer radius, and one State uses a two-plane subgrade so that the increase in depth is at a uniform rate from the center to the edges.

Next in importance to the general adoption of the thickened-edge design is the adoption of the longitudinal center joint in concrete pavements by a large majority of the State highway departments. Thirty-four States now definitely require a longitudinal joint and it is expected that the coming season will show an increase in this practice. The longitudinal joint, in addition to effectually preventing irregular and un-

sightly longitudinal cracking, acts as a permanent traffic line and permits of half-width construction. A number of States now require that the pavement be constructed one-half at a time in order to avoid detouring traffic during the construction and curing period. In most cases the joint is formed by a deformed plate of 16 or 18-gauge metal which produces a tongue-and-groove connection. A majority of the States also require dowels across the longitudinal joint but there is no general agreement as to whether or not these dowels should be bonded. In some States deformed bars are used to insure a bond and in others precautions are taken to prevent bonding.

The question as to whether or not expansion joints are required in concrete pavements is being given considerable study, as is the question of their proper spacing. The majority of States are using expansion joints at more or less regular intervals but a considerable

joint. There does, however, seem to be a general agreement that when dowels are used, provision should be made for free movement of the concrete by preventing the bonding of both ends of the dowels.

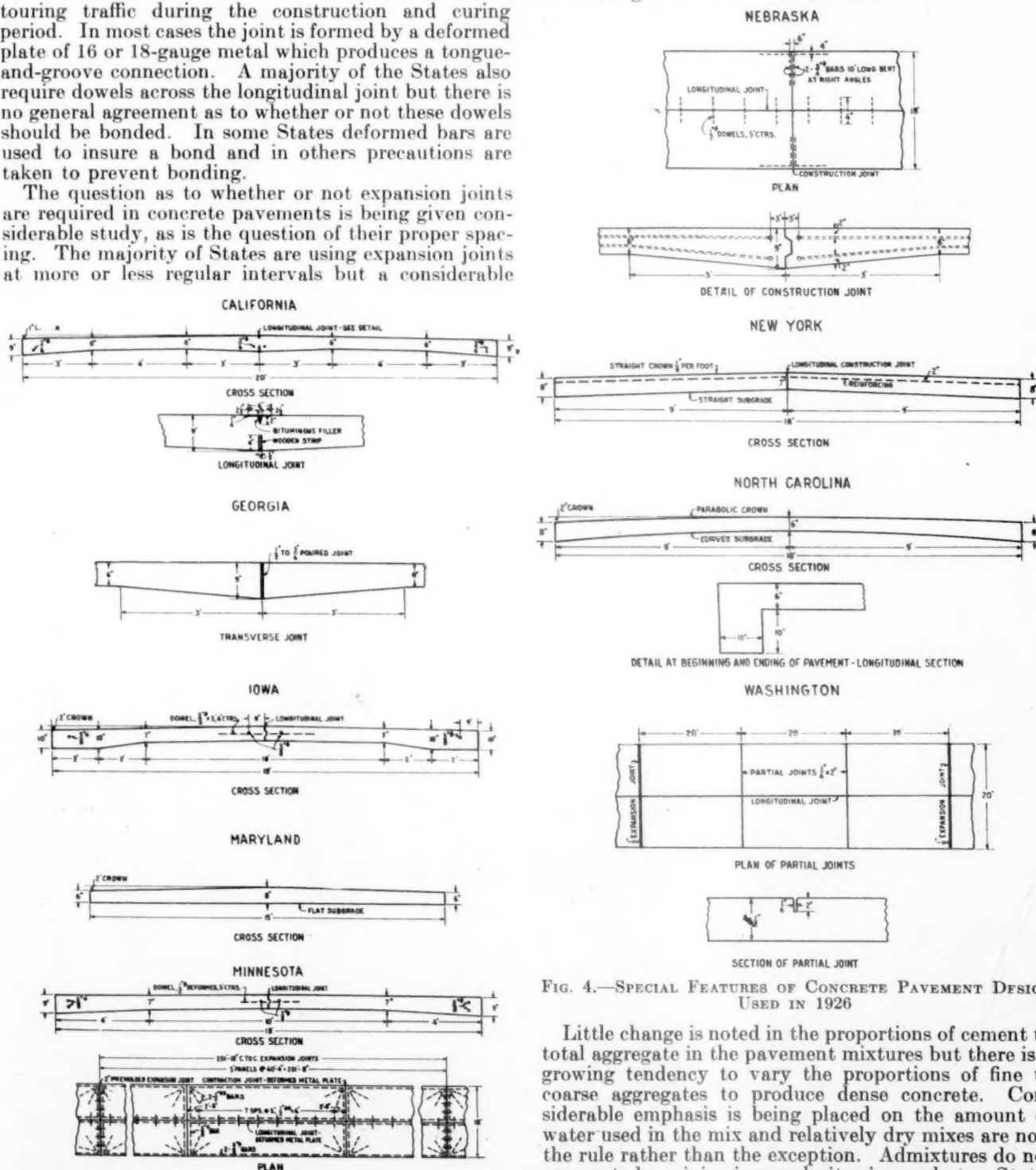


FIG. 4.—SPECIAL FEATURES OF CONCRETE PAVEMENT DESIGN USED IN 1926

FIG. 3.—SPECIAL FEATURES OF CONCRETE PAVEMENT DESIGN USED IN 1926

number of States do not consider them necessary. As yet no general agreement has been reached among the States using expansion joints as to their proper spacing and width, or the necessity of dowels across the

Little change is noted in the proportions of cement to total aggregate in the pavement mixtures but there is a growing tendency to vary the proportions of fine to coarse aggregates to produce dense concrete. Considerable emphasis is being placed on the amount of water used in the mix and relatively dry mixes are now the rule rather than the exception. Admixtures do not appear to be gaining in popularity since only two States use an admixture as a standard requirement. The use of special cement or special methods of manipulation to obtain high early strength is coming into use for emergency work, particularly in the construction of bridge floors, but does not appear to be considered for ordinary concrete pavement construction because of

TABLE 1.—General features of design of cross section of concrete pavements on Federal-aid projects submitted in 1936.

State <sup>1</sup>	Pavement cross section					Mix proportions	Reinforced type				
	Width	Thickness			Crown		Bars	Mesh	Location	Edge bars	Plain type
		Edge	Center	Edge							
	Feet	Inches	Inches	Inches	Thickened-edge width		Lbs. per 100 sq. ft.	Lbs. per 100 sq. ft.			
Alabama.....	18	9	6	9	3	2-inch, curved					No steel. Dowels only. Two 3/4-inch diameter smooth edge bars.
Arizona.....	18	9	6	9	2	1 1/2-inch, curved					Four 3/4-inch diameter deformed edge bars.
Arkansas.....	18	9	6	9	2	2 1/4-inch, curved					Dowels only.
California.....	20	9	6-9-6	9	3	1-inch, curved					Dowels only.
Colorado.....	18	9	6 1/2	9	3	1 1/2-inch, parabolic					Do.
Connecticut.....	18 to 20	8	8	8	3	2 1/4-inch, circular	56 to 63		Top or bottom		Do.
Delaware.....	18	9	6	9	3	2 1/4-inch, curved			2 inches from top		No steel.
Florida.....	18	9	6	9	3	1 1/2-inch, curved	40		do		Dowels only.
Georgia.....	18	9	6	9	3	2-inch, curved	44				Two 3/4-inch diameter smooth edge bars, painted or oiled.
Idaho.....	18	8	6	8	2	1-inch, curved					Do.
Illinois.....	18	9	6	9	3	2-inch, circular					Four 3/4-inch diameter edge bars.
Indiana.....	18	9	7	9	2 1/2	2-inch, curved					Four 3/4-inch diameter smooth edge bars.
Iowa.....	18	10	7	10	2	2-inch, curved					Two 3/4-inch diameter smooth edge bars.
Kansas.....	18	9	6	9	4	2-inch, parabolic					Two 3/4-inch diameter smooth edge bars painted or oiled.
Kentucky.....	16	9	6	9	2	2-inch, curved	42 (alternate types)	40 (alternate types)	2 inches from top		
Louisiana.....	20	9	6	9	2	2 1/2-inch, curved			do		
Maine.....	20	9	7	9	4	1 1/2-inch, curved	58		5 inches from top		No steel
Maryland.....	15	6	8	6	4	2 1/4-inch, circular	91		2 inches from top		
Massachusetts.....	20	8	8	8	3	2 1/4-inch, circular	95		2 inches from bottom		
Michigan.....	20	9	7	9	3	2-inch, curved	90 (alternate types)	55 (alternate types)	3 1/2 inches from top		Dowels only. Six 3/4-inch diameter edge bars.
Minnesota.....	18	9	7	9	2	1-inch, curved					Two 3/4-inch diameter smooth edge bars.
Mississippi.....	18	9	6	9	2	2-inch, circular					Two 3/4-inch diameter smooth edge bars.
Missouri.....	18	9	6	9	2	1 1/2-inch, curved					Two 3/4-inch diameter smooth edge bars, painted or oiled.
Nebraska.....	18	9	6	9	3	1 1/2-inch, curved					Corner bars, 3/4-inch diameter.
New Hampshire.....	18	9	6	9	3	2-inch, curved					
New Jersey.....	20	8	8	8	2	2-inch, parabolic	28 to 80 (alternate types)	26.4 to 72.2 (alternate types)	2 inches from top		
New Mexico.....	18	9	6	9	2	1 1/4-inch, parabolic			Top and bottom		
New York.....	18	9	6	9	7	1 1/2-inch, straight	80 (alternate types)	25	2 inches from top		No steel.
North Carolina.....	16 to 18	4 1/2 to 5 1/2	6	4 1/2 to 5 1/2	None. Parabolic.	2-inch, parabolic	72 to 74	63 to 65	do	4 1/2-inch diameter (4 1/4-inch diameter).	Dowels only.
North Dakota.....	20	9	6	9	3	3 1/2-inch, circular			2 1/2 inches from top		Two 3/4-inch diameter smooth edge bars, painted or oiled.
Ohio.....	18	9	7	9	2	1 1/2-inch, curved	As shown	56 (alternate types)	2 inches from top		Dowels only.
Oklahoma.....	18	9	6	9	2	2-inch, curved	32		4 inches from top		Do.
Oregon.....	20	9	7	9	3	1 1/2-inch, curved					No steel.
Pennsylvania.....	20	8	6	8	3	Curved.					Dowels only.
Rhode Island.....	18	8	8	8	3	2-inch, circular	32 to 45		2 inches from top		Do.
South Carolina.....	18	8	6 1/2	8	3	2-inch, parabolic			do		Two 3/4-inch square edge bars.
Tennessee.....	20	8	6	8	2	1 1/2-inch, parabolic			As shown		No steel.
Texas.....	20	9	6	9	2	1 1/2 to 2 1/4 inch, curved			2 inches from top		Dowels only.
Utah.....	18	9	6	9	2	1-inch, curved	As shown on plans.		As shown on plans.		No steel.
Vermont.....	18	7	7	7	2	2-inch, curved	40 1/2		Top and bottom		Dowels only.
Virginia.....	18	8	6	8	2	2 1/4-inch, curved					No steel.
Washington.....	20	7	6 1/2	7	2	1 1/2-inch, curved					Dowels only.
West Virginia.....	18	8	6	8	2	2 1/4-inch, parabolic					No steel.
Wisconsin.....	20	9	6 1/2	9	4	2-inch, curved					Dowels only.

<sup>1</sup> Four States, Montana, Nevada, South Dakota, and Wyoming submitted insufficient mileage to justify inclusion in the table.<sup>2</sup> Admixture of 0.1 cubic foot of hydrated lime per bag of cement.<sup>3</sup> Admixture of 0.08 cubic foot of hydrated lime per bag of cement.<sup>4</sup> Unreinforced section.<sup>5</sup> Reinforced section.

TABLE 2.—General features of design of joints in concrete pavements on Federal-aid projects submitted in 1926

State <sup>1</sup>	Longitudinal joint		Transverse joint				Dowels		Special features
	Type	Gauge or width	Type	Spacing	Width	Filler	Longitudinal joints	Transverse joints	
Alabama	Not required		Expansion	40	1/4	Prepared bituminous	1/2-inch diameter, 5 feet c. to c.	None	
Arizona	As shown on plans		do.	40	3/4	do.	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	do.	
Arkansas	do.		do.	50	1/2	Prepared or poured bituminous	None	Two, 4 feet by 1/2-inch diameter	See Figure 3 for longitudinal joint and cross section.
California	Submerged. (See fig. 3)		do.	50	1/2 to 3/4	do.	4 feet by 1/2-inch diameter, smooth, 5 feet c. to c.	None	
Colorado	Deformed metal plate	18	do.	60	1/2	Prepared bituminous	None	do.	Reinforcing in top on cuts, in bottom on fills.
Connecticut	Prepared or poured bituminous	1/4-in.	do.	40	1/2	Prepared or poured bituminous	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	Seven, 4 feet by 1/2-inch diameter, smooth, one end free	Admixture of hydrated lime.
Delaware	Deformed metal plate	16	Construction	( <sup>1</sup> )		Prepared or poured bituminous	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	do.	
Florida	Not required		Expansion	40	1/4 to 1/2	Poured bituminous	2 feet by 1/2-inch diameter, 21 inches c. to c.	None	See Figure 3 for thickened transverse joint.
Georgia	do.		do.	( <sup>1</sup> )	1/4 to 1/2	Prepared bituminous	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	do.	
Idaho	Deformed metal plate	14	do.	30	1/4 to 1/2	Prepared bituminous	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	do.	
Illinois	do.	16	Construction	( <sup>1</sup> )		do.	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	do.	
Indiana	do.	16	do.	( <sup>1</sup> )		do.	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	Six, 4 feet by 1/2-inch diameter, smooth, one end free	
Iowa	do.	18	do.	( <sup>1</sup> )		do.	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	Nine, 2 feet by 1/2-inch diameter, smooth, one end free	
Kansas	do.	18	Expansion	150	3/4	Prepared bituminous	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	None	See Figure 3.
Kentucky	do.	16	do.	30	1/2	do.	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	do.	Tongue and groove construction joint.
Louisiana	do.	16	do.	30	1/2	Prepared or poured bituminous	2 feet by 1/2-inch diameter, smooth, 3 1/2 feet c. to c., one end free	Seven, 4 feet by 1/2-inch diameter, smooth, one end free	Half-width construction required.
Maine	Poured bituminous filler	( <sup>2</sup> )	do.	40	1/2	Prepared bituminous	3 1/2 feet c. to c.	Eight, 2 feet by 1/2-inch diameter, smooth, one end free	Do.
Maryland	Not required	( <sup>1</sup> )	Construction	( <sup>1</sup> )	1/2	Poured bituminous	5 feet c. to c.	None	See Figure 3.
Massachusetts	Poured bituminous filler	( <sup>1</sup> )	Expansion	75 to 100	1	Prepared bituminous	5 feet c. to c.	Eight, 4 feet by 1/2-inch square, smooth, one end free	Half-width construction and admixture.
Michigan	Deformed metal plate	16	do.	200 3/4	2	do.	5 feet c. to c.	Six, 2 1/2 feet by 3/4-inch diameter, smooth, one end free	See Figure 3.
Minnesota	do.	16	do.	( <sup>1</sup> )	1/4 to 1/2	Prepared or poured bituminous	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	Ten, 4 feet by 3/4-inch diameter, smooth, one end free	See Figure 3.
Mississippi	do.	18	do.	50	1/4 to 1/2	do.	do.	None	
Missouri	do.	16	Construction	( <sup>1</sup> )		do.	4 feet by 1/2-inch diameter, 5 feet c. to c.	None	See Figure 4 for sketch of thickened, tongue and groove joint.
Nebraska	Deformed metal plate	18	do.	( <sup>1</sup> )		Prepared or poured bituminous	None	Eight, 2 feet by 3/4-inch diameter, smooth, one end free	Half-width construction required.
New Hampshire	Poured bituminous filler	( <sup>1</sup> )	Expansion	50	1/4 to 3/4	Prepared or poured bituminous	None	Nineteen, 3/4-inch diameter, smooth, one end free	Double line of reinforcing.
New Jersey	Prepared bituminous	1/2-in.	do.	34 1/2 to 45 1/2	1/2	do.	When shown	None	
New Mexico	As shown on plans		do.	30	3/4 to 1 1/2	Prepared bituminous	None	None	
New York	Plain butt joint		do.	40	1/2	do.	None	Eight or nine, 4 feet by 3/4-inch diameter, one end free	Half-width construction, see Figure 4.
North Carolina	Not required		Construction	( <sup>1</sup> )		do.	5 feet by 1/2-inch diameter	None	See sketch of drop curbs at pavement ends, Figure 4.
North Dakota	Deformed metal plate	( <sup>1</sup> )	Expansion	30	1/2	do.	5 feet by 1/2-inch diameter	None	Heavy crown.
Ohio	do.	18	Construction	( <sup>1</sup> )	1	Poured bituminous	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	Eight, 2 feet by 1/2-inch diameter, smooth, one end free	Expansion joint location pre-determined.
Oklahoma	do.	18	Expansion	50	1/4	Prepared bituminous	3 feet by 1/2-inch square, deformed, 3 feet c. to c.	None	
Oregon	do.	18	do.	25	1/4	do.	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	None	
Pennsylvania	do.	14	do.	( <sup>1</sup> )	1/2	do.	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	None	
Rhode Island	Plain butt joint		do.	100	1/2	do.	2 feet by 1/2-inch square, 3 feet c. to c.	Eight, 2 feet by 1/2-inch diameter, smooth, one end free	
South Carolina	Not required		do.	40	1/4 to 1/2	Prepared or poured bituminous	4 feet by 1/2-inch diameter, 5 feet c. to c.	None	
Tennessee	Deformed metal plate	18	do.	30	3/4	do.	4 feet by 1/2-inch diameter, 5 feet c. to c.	None	
Texas	do.	18	do.	60 to 100	1/4 to 1/2	do.	4 feet by 1/2-inch diameter, 5 feet c. to c.	Six, 4 feet or 5 feet by 1/2 or 3/4-inch diameter, smooth, one end free	
Utah	do.	18	do.	40	1/4 to 1/2	do.	4 feet by 1/2-inch square, 5 feet c. to c.	None	
Vermont	Poured bituminous filler	( <sup>1</sup> )	do.	43 1/2	1/2	do.	2 feet by 1/2-inch diameter, deformed, 3 1/2 feet c. to c.	Eight, 2 feet by 1/2-inch diameter, smooth, one end free	Tongue and groove construction joint.
Virginia	Not required		Construction	( <sup>1</sup> )	1/4 to 1/2	Poured bituminous	2 feet by 1/2-inch diameter, deformed, 3 1/2 feet c. to c.	None	See Figure 4 for sketch of contraction joint.
Washington	Poured bituminous filler	1/4-in.	Expansion	60	1/4 to 1/2	do.	2 feet by 1/2-inch square, smooth, 1 1/2 feet c. to c.	None	
West Virginia	Deformed metal plate	16	Construction	( <sup>1</sup> )	1/2	Prepared bituminous	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	None	
Wisconsin	do.	18	Expansion	31 1/2	1/2	do.	4 feet by 1/2-inch diameter, deformed, 5 feet c. to c.	Four, 4 feet by 1/2-inch diameter, one end free	

<sup>1</sup> Four States, Montana, Nevada, South Dakota, and Wyoming, submitted insufficient mileage to justify inclusion in the table.<sup>2</sup> Paint coat.<sup>3</sup> Not shown.<sup>4</sup> Designed.

the large increase in cost. In general, the mixtures specified for concrete pavements range from 1:2:3 to 1:2:4, although certain States specify a cement-sand ratio of 1:1½ or 1:1¼ for special aggregates.

Less steel per square yard of pavement is now used as reinforcement than formerly, although the total amount of steel used, including edge bars, dowels, and metal joints is probably greater. Only seven States, six of which are located in the northern part of the country where the soil freezes to considerable depth, specify bar mats in preference to fabric reinforcement. The majority of States using a reinforced design specify fabric or permit either fabric or bar types to be used.

Figures 3 and 4 show sketches of some unique and interesting features of design found in certain States. In compiling the data for Tables 1 and 2 effort was made to eliminate, so far as possible, such designs as appeared to be unusual and to select the one most representative of the usual practice in each State. Certain States have developed standard designs which are apparently used without variation, while other States vary such features as depth of pavement, mix, amount and position of steel reinforcement, spacing of transverse joints or the shape of the cross section to fit local conditions. In four States so few projects involving concrete pavements have been received that no general idea of their practice in designing could be obtained.



HALF-WIDTH CONSTRUCTION OF CONCRETE PAVEMENTS AVOIDS DETOURING DURING CONSTRUCTION

**Sand-clay and gravel surfacing.**—There does not appear to be any material change in recent years in the technic of constructing sand-clay roads, but the tendency in clay-bound gravel construction is toward the use of smaller sizes of gravel in the surface course. Experience in maintaining gravel roads under automobile traffic has shown that gravel larger than 1 inch in size is loosened and "kicked out" of the surface and any considerable amount of large gravel is likely to result in failure of the surface by ravelling.

**Bituminous macadam.**—In the construction of bituminous penetration macadam there has been a notable trend toward the use of stiffer binder. As an illustration of this change, the penetration test requirements in Ohio have been reduced from a range of 90 to 120 in 1923 to 85 to 100 in 1926 and in North Carolina 90 to 120 in 1922 to 80 to 100 in 1926, and in New York from 120 to 150 in 1923 to 100 to 120 in 1926. There is also a tendency, in this type of construction, to use larger and more uniform sizes of crushed stone and to reduce the depth of the top course from the 3 and 3½ inches formerly used to 2 and 2½ inches.

The reduction in the depth of the course and the use of larger and more uniform sizes of stone permits more complete and uniform penetration of the course, and, together with the stiffer asphalt, tends to eliminate

the development of corrugations in the surface under heavy traffic.

Protection of the edges of bituminous macadam by an extension of the base course has been adopted to a



A CALIFORNIA ROAD, ORIGINALLY A 24-FOOT BITUMINOUS CONCRETE ON A CONCRETE BASE, WIDENED TO 42 FEET BY THE ADDITION OF CONCRETE SHOULDERS AND A NEW ASPHALTIC CONCRETE SURFACE APPLIED

limited extent and this feature is standard design in Ohio.

**Bituminous concrete.**—The effect of research and wider experience in the construction and maintenance of bituminous concrete pavements is shown in the tendency toward more rigid requirements in grading the mineral aggregates. The practice of constructing this type of surfacing on a rigid base of Portland cement concrete appears to be gaining in favor, due to the difficulty in properly consolidating new macadam bases and also to the small differential in the cost of construction.

**Brick.**—Until rather recently grout-filled brick on a sand cushion and monolithic brick pavements were standard construction, but these types are now practically obsolete. All of the Federal-aid brick pavement projects submitted for several years have provided for the use of a bituminous joint filler. The practice of laying bricks flat rather than on edge is now so commonly adopted as to be accepted as standard construction.



OLD PENETRATION MACADAM IN MARYLAND RECONSTRUCTED AND WIDENED BY THE ADDITION OF NEW CONCRETE SHOULDERS AND NEW PENETRATION MACADAM TOP

Recent test results indicate that brick as thin as 2½ inches may be used for paving. The report on these tests<sup>2</sup> has been issued only recently and it is anticipated that the results will be reflected in designs submitted in the future.

(Continued on p. 20)

<sup>2</sup> Thin Brick Pavement Studied, PUBLIC ROADS, vol. 7, No. 7, September, 1926.

# PROPORTIONING CONCRETE AGGREGATES BY WEIGHT

By R. W. CRUM, Engineer of Materials and Tests, Iowa Highway Commission

IT HAS been demonstrated by numerous investigators that the strength of concrete depends upon the relation between the amount of cement in a unit volume and the total amount of solids in that volume. The weights of the materials are proportional to the volumes of solid material in the concrete, and it is therefore logical to express proportions by weight. Expressing proportions by weight also greatly facilitates computations of quantities of materials and the design of equivalent mixtures from dissimilar materials.

## MEASUREMENT BY WEIGHING RESULTS IN ACCURATE PROPORTIONING

If the fine and coarse aggregates in concrete are to bear a definite relation to each other, the advantages of weighing the aggregates, instead of measuring them, are obvious. Weighing provides a means of securing accurate quantities of materials for each batch, without the necessity of taking into account the bulking effect of moisture as in loose volumetric measure, and without additional cost. The contractor as well as the State has an accurate record of the actual amount of material used. The concrete is more uniform in quality, and the inspector can more easily control the measuring and mixing operations and make changes in quantities when necessary. Experience in Iowa with some 40 installations gives very convincing evidence that the equipment needed is inexpensive, easily installed, and can be rapidly operated.

The primary objective in measuring the ingredients for concrete by any method of measurement is to maintain definite and constant relationships between the constituents of successive batches. Accurate volumetric measurement may be possible, but in actual practice even with first-class inspection, accuracy equal to that of weighing can not be attained without extreme vigilance and expenditure of time. It has been found easily possible to weigh consistently to 5 pounds or less. In an ordinary five-bag batch of 1:2:3½ concrete this means a possible error of 0.3 per cent. If measured by volume in a straight-sided box having an area of 6 square feet, a variation of 1 inch in height in filling the box means a possible error of 3.5 per cent.

## WEIGHING AGGREGATE ADVANTAGEOUS FROM VIEWPOINT OF BOTH ENGINEER AND CONTRACTOR

The relative accuracy of the measuring method is, however, not the most vital factor. Even if the materials should be accurately measured by volume, changes in the moisture content of the sand might make relatively large changes in the batch. A large amount of research has been devoted to study of the bulking effect of moisture in sand and means of making corrections when measuring sand, but it is still common practice to ignore this factor where concrete is made in large quantities. The simplest solution is to weigh the materials and do away with the problem. The effect of moisture upon weight is very small as compared to its effect upon bulk, and the weight can be very quickly and easily corrected for the amount of moisture present.

Figure 1 shows the typical effect of moisture upon the bulk of sand. This effect is sufficient to produce an appreciable variation from theoretical proportions on practically every job where volumetric proportioning is used. Assuming that a 1:2:3½ mixture of dry materials measured by volume would require 1.42 barrels of cement per cubic yard to make concrete of 80 per cent density. If the sand used should contain 2 per cent of moisture, the cement content would be increased to 1.506 barrels per cubic yard—an increase of 6 per cent. Now if the materials

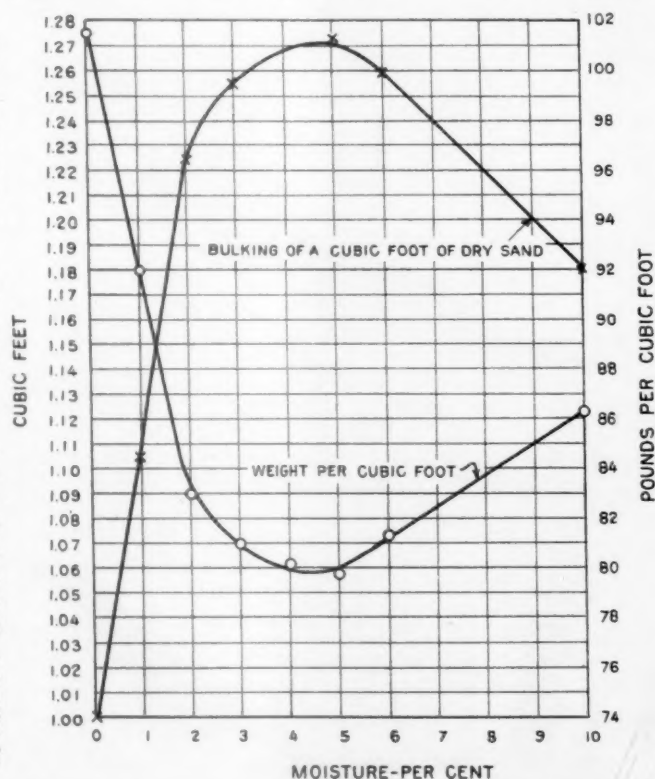


FIG. 1.—TYPICAL CURVES ILLUSTRATING EFFECT OF MOISTURE ON BULKING OF SAND

were to be weighed instead of measured by volume, the same result would be secured with dry materials, but with sand containing 2 per cent moisture the cubic yard of concrete would contain 1.43 barrels of cement, an increase of only 0.06 per cent. In other words, 2 per cent of moisture in the sand means an increase in the cost of cement, which is ten times larger when the materials are measured by volume than when they are measured by weight. Even this small increase could be lowered by correcting the batch weights for the moisture content.

Of course if proportions are based upon dry materials, any change in moisture with volumetric measurements will result in richer concrete, and hence the procedure may be safe, but there is a big advantage

in uniformity, and at least the contractor will recognize the advantage of not having the cement overrun the estimated quantity. The practice in Iowa is to run moisture determinations about six times a day or oftener and correct the batch weights accordingly.

One of the most serious criticisms of our concrete pavement work is the lack of uniformity in the quality of the concrete. There are, of course, a number of factors upon which the uniformity depends. Undoubtedly the accuracy of measurement of the various ingredients is one factor of major importance, and although improvement in this one thing will not entirely solve the problem, no solution can be had until the materials are measured with uniform accuracy.

#### CHANGE IN PRACTICE IN IOWA RESULTS IN MORE UNIFORM CONCRETE

The Iowa Highway Commission has for several years studied the composition of the concrete in the roads by making sieve analyses of samples taken once

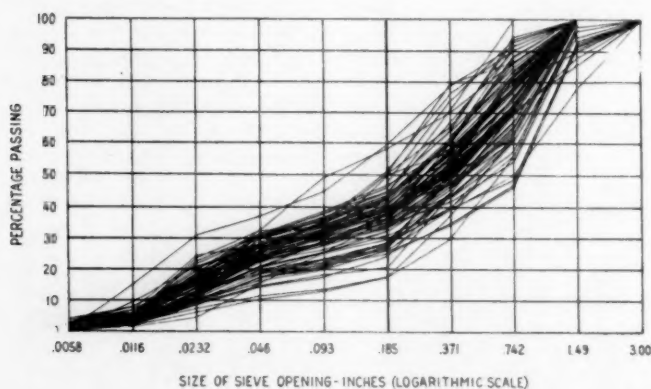


FIG. 2.—GRADING OF AGGREGATE ON A JOB WHERE VOLUMETRIC PROPORTIONING WAS USED. SAMPLES WERE TAKEN DAILY FROM THE CONCRETE AFTER PLACING AND THE CEMENT REMOVED BY WASHING

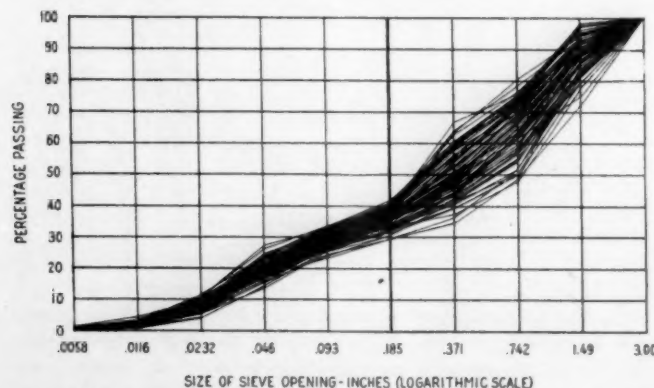


FIG. 3.—GRADING OF AGGREGATE ON A JOB WHERE MATERIALS WERE PROPORTIONED BY WEIGHT. SAMPLES WERE TAKEN DAILY FROM THE CONCRETE AFTER PLACING AND THE CEMENT REMOVED BY WASHING

each day from the road while yet wet. The cement is removed by washing and the aggregate remaining is dried and screened. Figure 2 shows these sieve analyses plotted for each day's run through a paving operation in 1921, and is typical of results secured by volumetric measurements, under first-class inspection.

According to the specifications, the mixture should have contained 34 per cent of fine aggregate. The

fine aggregate or sand is that part passing the No. 4 sieve having 0.185 inch square openings. As shown by the diagram (fig. 2) the proportions of the sand in the mixes actually passing the No. 4 sieve ranged from 18 to 60 per cent. Figure 3 is typical of results obtained since weighing was introduced in 1924. It will be observed that the sand content ranges only

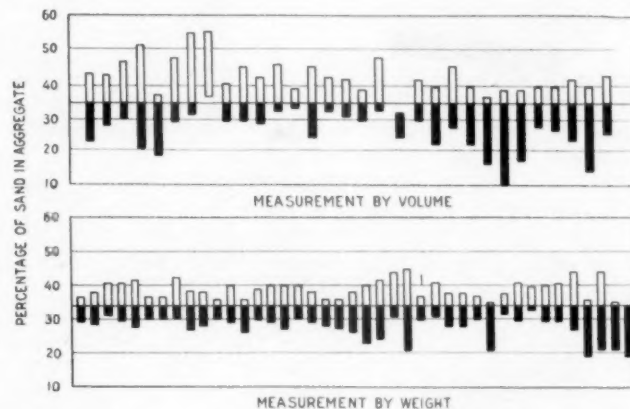


FIG. 4.—MAXIMUM AND MINIMUM PERCENTAGE OF SAND IN TOTAL AGGREGATE DURING A SEASON'S RUN ON A NUMBER OF JOBS, SOME OF WHICH PROPORTIONED BY VOLUME (PRIOR TO 1924) AND SOME BY WEIGHT. SAMPLES WERE TAKEN DAILY AND EACH BAR REPRESENTS THE EXTREME VARIATION ON ONE JOB. IN ALL CASES THE SPECIFICATION REQUIRED APPROXIMATELY 34 PER CENT SAND IN THE AGGREGATE

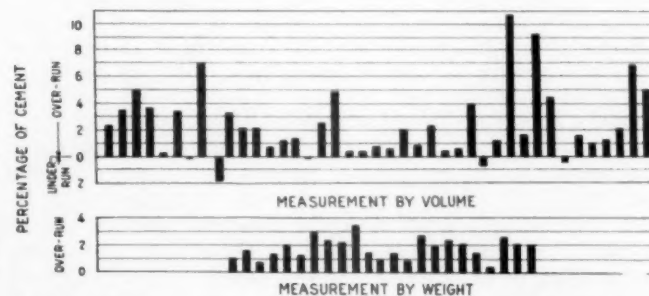


FIG. 5.—VARIATION IN USE OF CEMENT FROM THEORETICAL REQUIREMENT ON JOBS PROPORTIONING BY VOLUME (PRIOR TO 1924) AND BY WEIGHT. EACH BAR REPRESENTS A SEASON'S WORK WITH ONE MIXER

from 30 to 41 per cent. This is not perfect, but is undoubtedly an improvement. Figure 4 shows the maximum and minimum sand content of concrete during a season's work on a number of jobs, some of which proportioned by volume, and others by weighing.

Proportioning by weight rather than volume avoids errors due to bulking and permits of easy correction for weight of moisture and thus reduces overrun in cement and aggregates due to these factors—or, in other words, makes the yield more uniform. The estimated quantities of cement and aggregates are usually based upon dry materials, and therefore, in measuring by volume, moisture, especially in the sand, will increase the cement per cubic yard and decrease the yield. In weighing, however, accurate batches can be produced and the yield per barrel of cement kept more constant. Our experience is as follows:

Out of 41 contracts during the period from 1920 to 1923, with aggregates measured by volume, the maximum average overrun in cement for a season's work

on one job was 10.8 per cent, the greatest underrun was 1.8 per cent, and the average for all jobs was 2 per cent overrun. Out of 23 contracts during 1924 and 1925, with aggregates weighed, the maximum overrun in cement was 3.6 per cent, the minimum 0.3 per cent, and the average for all jobs was 1.8 per cent. Variations in slab thickness will always cause variations in recorded cement content per unit of volume,



BOTTOM DUMPING HOPPER SUPPORTED BY WEIGHING DEVICE USED AT A CENTRAL MIXING PLANT

and under rigid inspection the tendency will be to overrun. Data for 1926 are now shown for the reason that on account of the extraordinarily wet season, most of the contracts showed an unusually large overrun in materials, due to great difficulty in preparing subgrade. It would appear from the above data, which are shown graphically in Figure 5, that some improvement in uniformity was made.

A valuable result of the weighing of materials is the accurate record of the amount of material actually

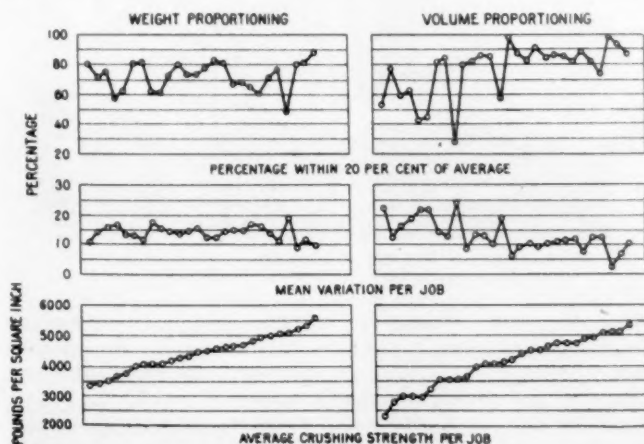


FIG. 6.—RESULTS OF COMPRESSION TESTS OF CYLINDERS MADE DAILY ON A NUMBER OF JOBS SOME OF WHICH PROPORTIONED BY WEIGHT AND SOME BY VOLUME. EACH POINT PLOTTED IS BASED UPON A SEASON'S WORK WITH ONE MIXER

used in the structure which is obtained. Since such materials are customarily bought and sold by weight, such a record should be of great value, especially to the contractor. At several times in the past few years settlements between the highway commission, contractors, material producers, and carriers would have been greatly facilitated had such a record been available. In one case, a paving contractor was billed

for sand and gravel and freight at such a rate that every cubic yard of concrete he made would have contained 3,900 pounds of sand and gravel. In the proportions specified, this would have meant the production of concrete of 105 per cent density. The producer of the material recognized this absurdity and settled for a more reasonable amount, but this settlement was on a guess and not based on facts as it would have been had the material been weighed when mixed.

#### STRENGTH OF CONCRETE PROPORTIONED BY TWO METHODS INVESTIGATED

There is no question but that the realization of the foregoing contractual advantages will result in closer bidding and reduction in cost to the public. Any reductions in construction uncertainties are bound to

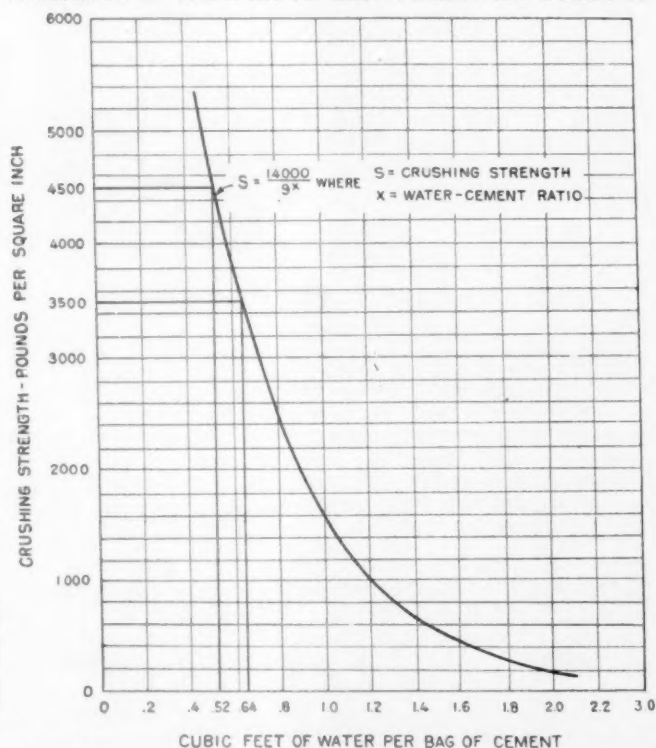


FIG. 7.—TYPICAL RELATION BETWEEN WATER-CEMENT RATIO AND CRUSHING STRENGTH OF CONCRETE. AN INCREASE OF 0.12 CUBIC FOOT OR 0.9 GALLON OF WATER PER BAG OF CEMENT LOWERS THE STRENGTH OF THE CONCRETE WITH A STRENGTH OF 4,500 POUNDS PER SQUARE INCH TO 3,500 POUNDS PER SQUARE INCH

have this effect. The method is, therefore, justified without reference to the quality of the concrete. However, since it must be admitted that accurate and uniform measurement of materials is the basis of uniform concrete, some improvement in uniformity of concrete by means of weight measurements should result. Examination of the tests of cylinders made from day to day upon the paving jobs indicates this improvement to a limited extent only. The same range of strengths in individual specimens appears on the weighed-aggregate jobs as on those in which the aggregates were measured by volume. However, comparison of the average strengths of all of the different jobs from 1921 to 1926 indicates that the job averages on weighing jobs are more uniform. This conclusion is supported by the data shown in Figure 6. Also the percentage of specimens from the various jobs falling

within 20 per cent of the average strength appears to be the more uniform for the weighed aggregate jobs.

It would appear from study of these data that there must be some other variation in measurement that affects the uniformity of the strength. With the cement and aggregates accounted for, it is obvious that in order to secure the full benefit of the improved methods described, refinement must be made in the control of the water content of the batches. Data from many sources have established that the relation between water, cement, and strength may be expressed by a curve of the form shown in Figure 7. Since concrete of comparatively high strength is used on con-



BOTTOM DUMPING HOPPERS BENEATH BIN SUPPORTED BY PLATFORM SCALES

crete paving work, reference to the curve for strengths from 3,000 pounds per square inch up will demonstrate forcibly that on such work the effect upon strength of a comparatively small variation in water content is very large.

Special investigations were made on two jobs where the aggregates were accurately weighed and the water-measuring devices were considerably better than ordinary, with the rather astonishing result that we found a variation in water-cement ratio in fresh concrete of from 0.684 to 1.072 cubic foot of water per bag of cement in one case and from 0.648 to 0.959 cubic foot per bag in the other. According to data published by Abrams, Talbot, and others, this variation in water-cement ratio would easily account for variation in strength of 100 per cent. The mixer operator and inspector were trying to maintain a uniform consistency while the observations were made. About seven samples per day were taken for three days. The engineer who made this investigation reported that carelessness in handling cement was a considerable factor in this variation. It is evident that more accurate methods for controlling the water-cement ratio must be developed, if we are to realize the maximum benefits from other refinements such as weight proportioning.

#### WEIGHING FOUND TO BE A PRACTICAL METHOD

There have proven to be no practical difficulties in handling aggregates by weight. The equipment cost is negligible and the time element is not a factor. The rate of production has not been influenced by this method of weighing. The best evidence of the advantage to the contractor is the unanimous approval given by the contractors who have worked under this

system for three years. This was recently expressed at a meeting of the paving section of the central branch of the Associated General Contractors of America. The weighing of aggregates has been standard practice in Iowa for three years and is far past the experimental stage.

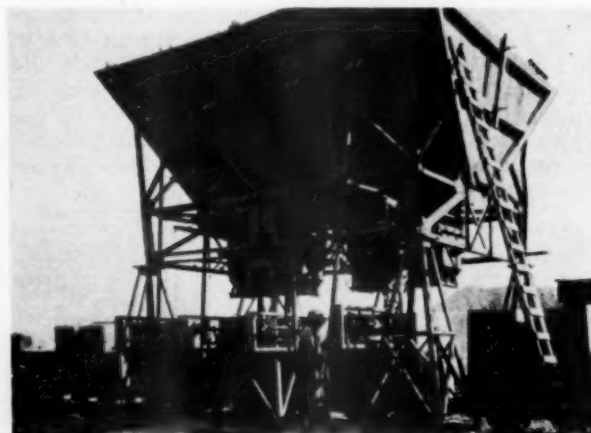
Several varieties of weighing apparatus have been successfully used. Simple field-built bins and hoppers used with ordinary platform or mill scales have been used as well as permanent equipment designed and built by manufacturers of paving equipment.

Four general types are in use, as follows:

1. Bottom-dumping hopper on lever-weighing system with direct reading dial scale.
2. Batcher device adapted to weighing system, usually with pipe lever scales.
3. Bottom or side dumping hopper on platform scales.
4. Hopper mounted on movable scales for loading industrial railway boxes.

In the experience of the Iowa Highway Commission those installations have been found most satisfactory which are so arranged that the scale beam and operator are at the same elevation as the weighing hopper, so that the operator can observe the inside of the hopper and easily remove excess material if necessary.

The operation of a weighing plant, of course, involves thorough inspection. It is the inspector's duty to make sure that the scales are always in proper working order, to calibrate them frequently, and to see



BATCHER DEVICE WHERE MATERIALS ARE WEIGHED BY AN ARRANGEMENT OF PIPES AND LEVERS

that the correct amount of material goes into each batch. The latter point involves frequent determinations of the moisture content of the aggregate and making the necessary corrections.

It would seem, since the weighing method provides a more accurate means of securing the specified amounts of materials in every batch, thereby removing one obstacle to the production of more uniform concrete, and since this can be done without extra cost, that we are justified in requiring this procedure. In the opinion of the Iowa Highway Commission this procedure marks a distinct advance in the technic of constructing concrete pavements or bases for other types of pavement.

## CONCRETE BRIDGE TO BE TESTED TO DESTRUCTION

An unusual opportunity to test to destruction a large concrete bridge of modern design has been presented in North Carolina. A dam is now under construction on the Yadkin River which will cause the impounded water to entirely submerge the bridge across the river between Albemarle and Mount Gilead.

This bridge was built by the State in 1922 as a Federal-aid project and consists of three open-spandrel arch spans of about 150 feet each and 14 T-beam or deck-girder spans of approximately 40 feet each. The over-all length from face to face of the ends bents is 1,069 feet.

A cooperative agreement has been entered into between the North Carolina State Highway Commission and the Bureau of Public Roads for the making of as complete tests as possible before the bridge is submerged. It is believed that the results may be of great value to the engineering profession and in order to secure the best technical direction possible several organizations have been invited to appoint a representative on an advisory committee to take charge of the direction of the tests. An invitation has been extended to the following organizations:

- University of North Carolina.
- North Carolina State College.
- American Association of State Highway Officials.
- American Society of Civil Engineers.
- American Railway Engineering Association.
- American Concrete Institute.
- Highway Research Board.
- Bureau of Standards.
- American Society for Testing Materials.

At the present time all but two of these organizations have accepted the invitation. It is proposed that the advisory committee will formulate the test program and assume direction of the work from the technical standpoint. The program will be financed and carried out by the North Carolina Highway Commission and the Bureau of Public Roads.



YADKIN RIVER BRIDGE

The period during which the loading tests may be carried on will be limited to the interval between the time when it will be possible to close the bridge to traffic and the time when the bridge will be submerged by the water impounded by the dam. With this time limitation in view it will be necessary to make very complete preliminary arrangements for the work.

## DISPOSITION OF MOTOR-VEHICLE FEES AND GASOLINE TAXES IN IDAHO AND UTAH

Attention has been called to the need for a more complete statement of the disposition of motor-vehicle and gasoline-tax revenues in Idaho than that contained in the article "The collection and disposition of motor-vehicle revenues" in the January issue of Public Roads.

The county assessors who collect the license fees are directed to remit 10 per cent of their collections to the State treasurer, who places these payments in the State highway fund to be used for the maintenance of State highways only. Ninety per cent of the fees collected accrue to the counties. Collection costs are paid out of funds appropriated for the department of law enforcement, and therefore the gross collections are divided between the State and counties.

All of the revenue from the gasoline tax is placed to the credit of the State highway fund from which the costs of administering the law are paid. The net proceeds may be used for either maintenance or construction at the discretion of the Commissioner of Public Works. No part of the gasoline-tax revenue accrues to the counties.

In the article referred to Idaho was incorrectly included in the group of States which distribute the gasoline tax and the license fees in the same manner. In this State the counties receive 90 per cent of the license fees and the State 10 per cent and the entire net proceeds of the gasoline tax accrues to the State.

In the same article it was stated that the gasoline-tax receipts in Utah are placed to the credit of a fund for payment of interest and sinking fund charges on State road bonds. This statement was incomplete, as all ex-

cess revenues are placed to the credit of the highway fund for the construction and maintenance of roads. In 1926 the highway fund derived \$1,000,000 from this source.

## BOND OF PILE HEADS IN CONCRETE FOUNDATIONS TO BE TESTED

The Bureau of Public Roads is planning a series of tests to determine the bond strength developed between the heads of foundation piles and concrete foundation seals and to investigate methods of anchoring reinforcing steel to pile heads. It is planned to make these tests at an early date in order to secure information for the design of Federal-aid bridges which have been proposed for the Gulf region. In the design of these bridges special attention is to be given to the pier designs in order that they may be capable of withstanding large overturning moments due to high winds.

Six series of tests are to be made at the Arlington experiment station of the bureau. Short sections of water-soaked timber piles will be incased in blocks of 1:2:4 concrete representing the foundation seal. Plain cylindrical piles and pile heads which have been expanded by means of wooden wedges are to be used and will be pulled from the concrete by means of hydraulic jacks.

The relative effectiveness of different methods of anchoring reinforcing steel to pile heads is also to be determined. These tests will include hacked bars driven into pile heads, bars with fox-bolt ends driven into pile heads, and special steel pile rings designed for the attachment of reinforcing bars. The anchorage developed will be determined by pulling the steel from the pile head in a large testing machine.

(Continued from p. 6)

One section of the Gansevoort road in New York shows no defects while an adjoining section is a total failure, the difference again being due to change in subgrade.

W. F. Purrington, of the New Hampshire Highway Department, points out that a section of gravelly soil road treated with bituminous materials has now accommodated traffic through two winters, while wheels sank to their hubs where the road was not treated. It is plainly indicated that additional support is afforded by this simple treatment which may warrant a reduction in the thickness of gravel, macadam, or bituminous roads laid on such surfaces.

East of Cleveland, Ohio, brick surfaces laid on 4-inch concrete base have been in service for years, while a brick road laid on a 6-inch concrete base south of Cleveland was not adequate. In this case, the difference in subgrade support had a value of several thousand dollars per mile.

In a survey of 1,277 miles of California roads in 1920 it was found that no failure occurred on sand subgrade, 24 per cent of the failures occurred on loams and 76 per cent occurred on adobe and clay subgrades.

The State of Delaware has found concrete with a 5-7-5 cross section more satisfactory in some locations than concrete with a 6-8-6 cross section in others. The difference in support in these instances has had a money value of at least \$3,000 per mile.

Some of these examples may be considered as extreme, and in some cases variables other than support may be factors, but they serve at least to indicate the possible economic savings which may result from the intelligent suiting of pavement design to subgrade condition.

(Continued from p. 14)

*Methods of reconstruction.*—The reconstruction of old pavements which have become badly worn or are of inadequate depth and width for present traffic is a problem of considerable magnitude in some of the States. In the majority of cases the old surfacing has

considerable value and the method of reconstruction adopted should conserve this value as far as possible. The method of widening old, narrow macadam surfaces adopted by the State Roads Commission of Maryland has been used on a large mileage in the State. At the edges of the old macadam surface, concrete shoulders are constructed. These are generally 2 feet in width and 8 inches in depth and are placed at an elevation which will permit resurfacing the existing macadam and at the same time eliminate the excessive crown found on many of the old roads. Resurfacing is done with either bituminous macadam or bituminous concrete. Excellent results are being obtained by this method at a moderate cost per mile. The same plan is being followed in other States and in some cases the side strips are made sufficiently wide to form traffic lanes. The resulting pavement is particularly pleasing to fast traffic because of the definite and ample separation of traffic.

Old concrete pavements have been successfully widened and resurfaced by constructing an additional layer of plain or reinforced concrete over the old pavement and extending the new slab beyond the edges of the old pavement. In such cases the new portion of the pavement is usually not less than 5 inches in depth at the center and thickened at the edges to equal the combined depth of old and new pavement. Contrary to expectation, such pavements have not shown any marked tendency to develop cracks along the edges of the old pavement or over cracks in the original surface. Old brick and bituminous pavements on concrete bases, as well as old macadam surfaces, have also been successfully resurfaced and widened by the same method.

Concrete roads have also been resurfaced with bituminous concrete, placing a first course which takes out the inequalities of the old surface and then the wearing course. Where additional width has been desired this has been secured in some cases by placing new concrete shoulders and in other cases by laying a strip of bituminous concrete base on each side of the old pavement and laying the surface course on both the new and the old construction.

## ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

*Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.*

### ANNUAL REPORTS

- Report of the Chief of the Bureau of Public Roads, 1924.  
Report of the Chief of the Bureau of Public Roads, 1925.  
\*Report of the Chief of the Bureau of Public Roads, 1926. 5c.

### DEPARTMENT BULLETINS

- No. 105D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.  
\*136D. Highway Bonds. 20c.  
220D. Road Models.  
257D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.  
\*314D. Methods for the Examination of Bituminous Road Materials. 10c.  
\*347D. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.  
\*370D. The Results of Physical Tests of Road-Building Rock. 15c.  
386D. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.  
387D. Public Road Mileage and Revenues in the Southern States, 1914.  
388D. Public Road Mileage and Revenues in the New England States, 1914.  
390D. Public Road Mileage and Revenues in the United States, 1914. A Summary.  
407D. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.  
\*463D. Earth, Sand-Clay, and Gravel Roads. 15c.  
\*532D. The Expansion and Contraction of Concrete and Concrete Roads. 10c.  
\*537D. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.  
\*583D. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.  
\*660D. Highway Cost Keeping. 10c.  
\*670D. The Results of Physical Tests of Road-Building Rock in 1916 and 1917. 5c.  
\*691D. Typical Specifications for Bituminous Road Materials. 10c.  
\*724D. Drainage Methods and Foundations for County Roads. 20c.  
\*1077D. Portland Cement Concrete Roads. 15c.  
\*1132D. The Results of Physical Tests of Road-Building Rock from 1916 to 1921, Inclusive. 10c.  
\*1216D. Tentative Standard Methods of Sampling and Testing Highway Materials, Adopted by the American Association of State Highway Officials and Approved by the Secretary of Agriculture for Use in Connection with Federal-aid Road Construction. 15c.  
1259D. Standard Specifications for Steel Highway Bridges, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road work.  
1279D. Rural Highway Mileage, Income, and Expenditures, 1921 and 1922.

\* Department supply exhausted.

### DEPARTMENT CIRCULARS

- No. 94C. TNT as a Blasting Explosive.  
331C. Standard Specifications for Corrugated Metal Pipe Culverts.

### MISCELLANEOUS CIRCULARS

- No. 60M. Federal Legislation Providing for Federal Aid in Highway Construction.  
62M. Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal Aid Highway Projects.

### FARMERS' BULLETINS

- No. \*338F. Macadam Roads. 5c.  
\*505F. Benefits of Improved Roads. 5c.

### SEPARATE REPRINTS FROM THE YEARBOOK

- No. \*739Y. Federal Aid to Highways, 1917. 5c.  
\*849Y. Roads. 5c.  
914Y. Highways and Highway Transportation.

### OFFICE OF PUBLIC ROADS BULLETIN

- No. \*45. Data for Use in Designing Culverts and Short-Span Bridges. (1913.) 15c.

### OFFICE OF THE SECRETARY CIRCULARS

- No. 49. Motor Vehicle Registrations and Revenues, 1914.  
59. Automobile Registrations, Licenses, and Revenues in the United States, 1915.  
63. State Highway Mileage and Expenditures to January 1, 1916.  
\*72. Width of Wagon Tires Recommended for Loads of Varying Magnitude on Earth and Gravel Roads. 5c.  
73. Automobile Registrations, Licenses, and Revenues in the United States, 1916.  
161. Rules and Regulations of the Secretary of Agriculture for Carrying Out the Federal Highway Act and Amendments Thereto.

### REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

- Vol. 5, No. 17, D- 2. Effect of Controllable Variables upon the Penetration Test for Asphalts and Asphalt Cements.  
Vol. 5, No. 19, D- 3. Relation between Properties of Hardness and Toughness of Road-Building Rock.  
Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.  
Vol. 10, No. 5, D-12. Influence of Grading on the Value of Fine Aggregate Used in Portland Cement Concrete Road Construction.  
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

UNITED STATES DEPARTMENT OF AGRICULTURE  
BUREAU OF PUBLIC ROADS  
STATUS OF FEDERAL AID HIGHWAY CONSTRUCTION

AS OF

FEBRUARY 28, 1927

STATES	FISCAL YEARS 1917-1926				FISCAL YEAR 1927				BALANCE OF FEDERAL AID FUND AVAILABLE FOR NEW PROJECTS				STATES
	PROJECTS COMPLETED PRIOR TO JULY 1, 1926				PROJECTS UNDER CONSTRUCTION				PROJECTS APPROVED FOR CONSTRUCTION				
	TOTAL COST	FEDERAL AID	MILES		TOTAL COST	FEDERAL AID	MILES		ESTIMATED COST	FEDERAL AID ALLOTTED	MILES		
Alabama	\$ 19,226,411.34	\$ 8,725,985.09	1,296.3		\$ 1,824,900.34	\$ 889,114.95	101.9		\$ 5,935,691.10	\$ 2,012,159.58	336.4		Alabama
Arizona	10,949,871.25	5,853,772.35	729.8		623,444.90	324,049.45	39.8		1,233,468.95	633,667.40	71.9		Arizona
Arkansas	19,364,644.50	7,585,695.35	1,553.0		2,597,594.32	1,351,942.35	197.1		2,952,466.90	1,372,942.98	265.3		Arkansas
California	27,142,594.90	13,003,532.30	1,058.0		5,958,412.31	2,906,144.34	199.6		8,618,176.97	4,069,081.90	166.3		California
Colorado	13,905,504.64	7,127,288.18	745.0		958,080.35	522,177.14	37.9		5,933,750.71	2,931,014.28	266.8		Colorado
Connecticut	5,414,267.19	2,100,585.80	117.1		684,612.28	285,175.74	13.6		5,659,674.28	1,930,586.95	76.4		Connecticut
Delaware	4,918,052.29	1,791,665.60	124.3		1,039,433.07	452,067.18	28.0		591,038.05	241,755.90	17.6		Delaware
Florida	3,332,890.26	1,824,362.32	132.9		3,042,021.75	1,507,476.34	90.8		8,263,428.41	3,669,984.30	201.2		Florida
Georgia	25,173,406.37	11,684,627.95	1,734.0		4,691,125.95	2,259,537.16	284.0		5,053,735.18	1,937,178.50	335.4		Georgia
Idaho	11,061,196.14	5,982,112.70	724.7		1,827,194.53	1,067,910.12	102.9		2,133,453.23	1,357,956.62	101.1		Idaho
Illinois	14,616,611.86	8,012,125.19	1,177.0		3,659,478.17	1,745,325.07	117.7		4,469,582.26	2,426,225.14	98.0		Illinois
Indiana	19,943,612.80	11,525,322.10	2,114.3		3,820,114.55	1,765,168.39	237.7		7,744,250.68	3,390,000.00	125.0		Indiana
Iowa	20,032,775.40	12,500,493.25	1,150.6		1,925,237.31	924,524.04	117.6		13,747,132.44	5,477,132.80	70.6		Iowa
Kansas	32,937,108.10	8,482,082.25	759.3		2,102,570.22	852,812.24	89.7		17,637,658.70	3,634,866.55	352.2		Kansas
Kentucky	20,737,706.10	8,482,082.25	759.3		2,102,570.22	852,812.24	89.7		17,637,658.70	3,634,866.55	352.2		Kentucky
Louisiana	13,820,682.68	6,144,739.59	1,055.9		1,270,509.72	662,031.47	94.5		4,735,504.68	2,244,036.30	205.5		Louisiana
Maine	8,747,552.76	4,132,571.39	303.6		1,605,850.58	598,324.28	48.4		2,462,132.74	891,354.43	68.0		Maine
Maryland	10,384,943.10	5,112,391.22	423.3		598,331.18	334,258.01	46.0		1,006,930.92	455,368.64	72.2		Maryland
Massachusetts	18,353,197.71	6,567,260.62	374.5		412,120.05	121,945.75	5.1		5,416,611.35	1,453,354.92	24.3		Massachusetts
Michigan	25,977,240.73	11,627,082.30	963.0		7,731,030.05	809,340.11	55.0		14,633,653.67	6,594,976.68	332.0		Michigan
Minnesota	37,170,915.95	15,585,115.56	3,181.9		7,323,652.52	3,460,023.11	46.1		3,933,511.04	1,110,598.90	226.6		Minnesota
Mississippi	16,146,089.52	7,414,534.10	1,129.0		1,346,403.10	670,574.93	94.8		7,693,231.26	3,749,082.00	335.9		Mississippi
Missouri	28,989,166.92	13,735,014.85	1,943.2		10,103,432.18	4,430,780.36	301.0		11,550,056.77	4,590,776.87	308.6		Missouri
Montana	11,400,983.91	6,333,465.89	1,054.9		1,294,329.52	857,203.60	82.8		1,597,637.01	1,365,957.90	131.6		Montana
Nebraska	11,533,401.62	5,474,202.52	1,769.3		2,940,403.15	1,402,628.17	273.6		12,144,413.90	5,919,933.10	131.0		Nebraska
Nevada	7,559,195.61	5,130,334.59	539.8		2,525,681.74	2,171,318.96	259.6		1,503,625.94	1,298,830.80	198.5		Nevada
New Hampshire	4,962,559.60	2,377,450.07	237.6		846,458.09	386,537.45	26.4		647,214.00	303,902.51	18.7		New Hampshire
New Jersey	16,346,301.01	5,098,342.21	230.3		5,891,939.07	2,397,022.27	26.0		4,500,662.42	855,223.56	55.0		New Jersey
New Mexico	12,404,337.77	7,319,657.38	1,427.0		121,933.61	73,716.96	15.6		3,315,395.06	2,351,013.57	278.5		New Mexico
New York	43,224,279.79	17,911,957.19	1,197.0		6,958,911.17	2,475,659.92	158.4		35,974,173.00	9,234,152.70	578.3		New York
North Carolina	27,009,419.47	11,177,337.94	1,257.9		5,677,355.00	2,274,655.41	124.7		4,380,616.71	2,025,475.49	135.6		North Carolina
North Dakota	12,313,311.40	6,031,859.78	2,193.1		3,472,943.67	1,569,657.08	506.1		4,470,634.72	2,455,214.07	656.2		North Dakota
Ohio	47,032,332.90	17,371,787.03	1,354.1		3,752,879.85	1,541,246.32	123.1		13,315,033.35	4,497,869.14	352.5		Ohio
Oklahoma	28,247,950.33	13,159,999.15	1,178.9		1,177,814.08	553,488.56	47.0		3,773,977.26	1,605,652.90	212.8		Oklahoma
Oregon	17,027,878.42	8,593,214.79	939.2		887,891.19	514,971.40	34.9		3,087,601.65	1,701,704.69	115.7		Oregon
Pennsylvania	61,355,150.80	21,550,732.04	1,199.8		8,414,739.29	2,396,977.77	174.0		12,453,423.80	6,205,435.96	432.5		Pennsylvania
Rhode Island	3,988,616.09	1,588,829.05	86.7		1,244,737.29	435,650.00	29.3		778,986.12	205,665.00	13.7		Rhode Island
South Carolina	15,020,639.80	6,765,322.53	1,481.9		1,873,240.10	711,908.31	75.3		5,443,273.30	2,289,660.84	197.0		South Carolina
South Dakota	17,469,373.19	8,603,826.97	2,181.2		1,469,691.90	744,524.46	261.5		3,276,531.50	1,718,482.12	571.4		South Dakota
Tennessee	21,624,631.57	10,276,584.02	730.0		1,599,773.61	747,432.21	49.9		9,322,268.24	3,953,994.70	265.0		Tennessee
Texas	69,183,673.48	27,440,254.72	4,300.2		6,271,386.68	2,700,231.95	387.9		16,396,968.34	7,348,945.18	656.2		Texas
Utah	8,253,178.03	5,098,440.68	546.4		825,959.14	615,614.05	75.1		1,376,360.14	1,376,360.14	133.9		Utah
Vermont	4,242,042.64	2,017,659.51	134.6		652,242.02	235,362.78	11.1		1,118,369.27	648,678.78	32.0		Vermont
Virginia	21,990,249.44	10,385,728.11	1,005.5		3,212,343.00	1,417,440.95	100.2		4,831,900.00	2,056,910.00	131.1		Virginia
Washington	17,079,571.63	7,742,305.48	661.6		1,105,996.34	453,542.49	42.5		3,543,979.27	1,695,600.00	61.1		Washington
West Virginia	9,473,716.44	4,141,062.65	32.9		951,130.88	432,585.36	26.9		5,555,943.10	2,212,506.59	164.3		West Virginia
Wisconsin	24,865,508.19	10,382,705.73	1,562.1		1,977,504.19	898,747.18	95.1		7,843,531.07	3,514,754.99	322.5		Wisconsin
Wyoming	10,523,502.86	6,040,987.05	1,131.5		1,075,438.00	1,075,438.00	172.0		1,105,100.00	1,105,100.00	167.7		Wyoming
Hawaii													Hawaii
TOTALS	866,632,834.36	426,178,703.59	52,525.6		130,052,415.95	58,771,933.48	6,011.9		332,774,909.80	139,974,396.02	13,112.6		TOTALS

\* Includes projects reported completed (final vouchers not yet paid) totaling: Estimated cost \$ 94,199,742.31 Federal aid \$ 40,222,316.15 Miles 3,712.7